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AEROBIC-ANAEROBIC WASTE TREATMENT PROGRESS STUDIES

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THE OHIO STATE UNIVERSITY

[redacted]

Final Report on

AEROBIC-ANAEROBIC WASTE TREATMENT PROGRESS STUDIES

Project No. T - 1056

Submitted to

Robert A. Taft Sanitary Engineering Center
at the termination of
Contact Nos. SAph - 70889
and SAph - 74153

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Prepared by:

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July 1, 1961

THE OHIO STATE UNIVERSITY
ENGINEERING EXPERIMENT STATION
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July 1, 1961

Mr. T. W. Bendixen, Project Officer
Robt. A. Taft Sanitary Engineering Center
U. S. Publich Health Service
4676 Columbia Parkway
Cincinnati 16, Ohio

Dear Mr. Bendixen:

The attached report represents the fifth and final progress report of the studies being conducted at the Ohio State University on the efficiency of several combinations of processes used in the treatment of domestic sewage for small installations. This report is the terminal report for the contract period ending June 30, 1961 under contract No. SAph - 74153. Previous reports were presented to cover contract No. SAph - 70889. The results of all previous progress reports are incorporated in this report. Minor corrections have been made to some of the data presented in earlier reports.

This work has been supported by a contract with the Department of Health, Education, and Welfare, Publich Health Service, Robert A. Taft Sanitary Engineering Center in Cincinnati, Ohio. Mr. James B. Coulter and yourself have been the Project Officers for this study. We wish to acknowledge, with thanks, the interest you have shown in this project.

Respectfully submitted,

Kenneth W. Cosens

Kenneth W. Cosens, Associate Professor
Civil and Sanitary Engineering

KWC

Aerobic-Anaerobic Waste Treatment Studies

One of the great problems of modern sprawling suburban development is providing adequate facilities for waste water disposal. While most of us would agree that the most satisfactory method of disposal of domestic sewage is by means of large municipal plants there are a number of factors which prohibit the disposal of all sewage in these large plants.

Small disposal plants are needed for rural motels, schools, restaurants, small industries or commercial establishments, small subdivisions, single family dwellings or any habitation located where it is not served by a municipal sewerage system. In recent years quite s number of waste treatment unit operations have been developed or scaled down from the more successful unit processes used by large municipalities. The problems associated with selection or development of the most satisfactory unit processes, and how to operate them, have not been fully resolved.

One of the most common methods of disposal of sewage at small installations has been the use of conventional, horizontal flow settling tanks, usually called septic tanks, followed by tile field seepage systems. It has been disturbing to find so little published about the efficiency of these systems. The septic tank not only acts as a settling tank but a sludge accumulator and digester. The tile absorption field works quite satisfactorily under certain ideal conditions. There are many large areas of the country where absorption fields are quite unsatisfactory for a variety of reasons. Outstanding among these reasons are seasonal high ground water table, relatively impervious soils, small building sites and outcropping fractured limestone rock formations from which well water supplies may be polluted by these same disposal systems.

It is not inconceivable that reliable economical unit processes may be developed which will render domestic liquid wastes acceptable for ultimate disposal through storm drainage systems. It would be desirable to develop waste disposal processes in small plants to the point where the liquid effluents might be discharged to surface drainage structures near habitations. The quality of such effluents would have to approach the quality of surface waters used for public beaches and bathing purposes.

This report covers a study undertaken to determine the efficiency of operation and the parameters which measure the efficiency of at least three treatment unit processes used in small waste treatment plants. The first treatment unit is an upflow settling, digestion tank or anaerobic solids contact tank from which the solids are normally to be removed after several years accumulation. Liquid effluent from this primary unit is subjected to aeration in a secondary tank having two compartments, the first providing aeration and the second providing settling and

sludge return to the first compartment. Schematic plan and profile of this plant is shown in Figure No. 21. During the last six-month period of operation of this plant the raw sewage was placed directly into the aeration unit. The primary settling tank was completely bypassed and not used in the process. Treatment involved aeration and a short period of settling in the final part of the aeration unit.

A fairly weak domestic combined sewage is delivered to this pilot plant at a volumetric rate which is maintained constant throughout each 24-hour period. After treatment in the pilot plant the effluent is returned to the municipal sewage collection system from which it was taken.

Objectives of the Study

The specific objectives originally agreed upon were to determine capacity needed and the operational difficulties involved in treating normal domestic sewage in two unit processes to produce an effluent having the following properties:

1. Not more than 10 mg/l of 5 day BOD.
2. Not more than 10 mg/l of suspended solids.
3. A coliform MPN not more than 1000 per 100 ml.

It was further agreed that the primary unit process would be the anaerobic contact process followed by a secondary process involving complete aerobic treatment. Later in the project it was decided that the primary process was to be bypassed and full treatment to be consummated within the aeration unit and its settling compartment. These investigations were to be designed to provide information on the following points:

1. Capacity required in both the contact and aeration units per unit of volumetric and organic loading.
2. Amount of diffused air per unit load required to accomplish aerobic digestion.
3. Rate of sludge or scum accumulation in both the contact and aeration compartments.
4. Operational difficulties and maintenance requirements for the application of a scheme incorporating these two unit processes to the problems of small installations such as trailer courts, motels, shopping centers, and schools.

Description of the Research Facilities

Domestic sewage is pumped from a large City of Columbus sewer which collects sewage from a predominately residential and commerical area. Some storm water is present in the sewage, therefore during wet weather the sewage is weaker than during dry weather. The sewage is delivered to the site of the U.S.P.H. Service Plant at the rate of approximately 50 gpm and discharges over a triangular weir. This provides a constant level or head tank from which flow for the subject pilot plant

was taken at the rate of 895 gallons per day when the plant was operated as a two-unit plant and at the rate of 764 gallons per day when operated as a one-unit plant.

All sewage for the pilot plant passes through a 1/2 inch mesh hardware cloth. This screening was provided to eliminate serious difficulties anticipated in splitting and directing small flows through the research plant, especially through the volumetric feeder and overflow devices.

After screening, the sewage passes into the holding tank of the feeder mechanism. Volume of sewage fed to the pilot plant is controlled by a Roto-Dip-liquid feeder which consists essentially of a variable speed bucket wheel which feeds sewage to the unit processes. The number of revolutions of the feeder are recorded on a counter. Excess flow into this unit is automatically bypassed to the plant effluent line. This piece of equipment was calibrated and is checked for accuracy of flow delivery every few days. It was necessary to decrease the size of the holding tank so that it would not act as a sedimentation chamber. Since this slight difficulty was remedied this piece of equipment has operated perfectly.

This plant operated over a period of 22 months, the first 16 consisting of operation with two unit processes involving two tanks, the last 6 months involving just one unit process. During the first period of operation the sewage was discharged from the feeder to a 4" vitrified clay pipe which terminated, in a vertical leg, just 4" above the bottom of the primary tank. This primary tank is 4.76 feet deep and provides a surface area of 26.8 square feet. Total liquid volume is 960 gallons. Flow is upward through a sludge blanket which forms in this tank. After an initial break-in period this process provides not only sedimentation but a form of filtration and sludge solids contact. The effluent passes under a shallow baffle which prevents floating solids from leaving this primary unit. For all practical purposes there have been no floating solids on the surface of the primary settling tank.

Discharge from the solids contact tank takes place through a 4 inch pipe having its invert about 6 inches above the bottom of a sampling box. At this point it is possible to select undisturbed primary effluent samples.

From the first sampling box the flow enters a 4" clay pipe which terminates in an elbow just below the water surface in the aeration compartment of the secondary treatment tank. The aeration compartment has 6.46 ft. water depth, surface area of 11.4 sq. ft. and a volume of 550 gallons. Compressed air is diffused at the bottom of this tank by means of a Carborundum diffuser tube that is 2-1/2 " O.D. x 24 " long and has a permeability of 62. Permeability is the cubic feet per minute of free air at 70^0 F and 10 to 25 % humidity which will pass one square foot of diffuser medium to the atmosphere under a pressure of 2 inches of water. The settling compartment of the secondary unit has a surface area of 5.2 sq. ft., a depth of 6.46 ft. and a volume of 185 gallons. Baffles across the full width of the tank form the settling compartment.

No scum has formed on the two compartments of the secondary unit except during the last 6-month period of operation of the plant. After a brief period of shutdown when no air or sewage was delivered to the plant a floating layer formed on the settling compartment which was about 3 inches thick. It probably came from dislodged solids from the bottom of the aerator which were forced to float when the plant resumed operation. They were never removed from the tank surface.

Several times white sudsy foam has formed on the surface of the aerator, especially when the solids content of the mixed liquor is low. This foam disappears when the settleable solids begins to develop to a satisfactory concentration.

Following the aeration tank is another sampling box from which undisturbed representative samples of plant effluent may be collected. Effluent from this plant returns by gravity to the Columbus sewage collection system.

During the second period of operation, involving 6-months, the primary solids contact settling tank was completely bypassed and the raw sewage was discharged directly into the aeration tank. Rate of sewage flow was reduced as shown by the data given in Table No. 13.

Mode of Plant Operation

During the first 16 months of operation of the plant raw sewage flow averaged 895 gallons per day which caused the primary solids contact tank to provide a theoretical detention of 25.8 hours. At this rate of flow the aerator provides 14.8 hours detention and the final settling compartment provides 5.0 hours. Total treatment time in this plant averaged 45.6 hours over the first period of operation shown in Table No. 13.

It was decided that during the last six months of plant operation that the solids contact settling tank would be cut out of the process to determine what effect this would have on the efficiency of the aeration part of the plant. Flow rate was adjusted to 764 gallons per day which controlled the theoretical detention period in the aerator at 17.6 hours and 5.9 hours in the final settling compartment. Total treatment time now averaged 23.5 hours.

Air has been provided by four different types of compressors during the period of operation of this plant. For the first three months of operation air was compressed by means of a small Gast rotary type, carbon vane air compressor, Model No. 0211-P3A-G8X, rated at 0.7 cfm of air at 10 psig. It was driven by a 1/6 HP 1750 RPM motor. On October 31, 1959 a positive displacement air compressor, operating on a storage tank and releasing air through a pressure reducing valve, was installed and used for the months of November and December. This compressor was rated at 2.7 cfm at 80 psig, had a 12" x 26" storage tank and was driven by a 1/2 HP - 1750 RPM electric motor. It was not suited for this type of service and was replaced by a used Gast rotary type, carbon vane compressor which went into service when the plant started operation Feb. 11, 1960.

The Gast compressor in use in February 1960 was Model No. 0440, driven by a 1/4 HP electric motor. Its capacity gradually decreased, with wear, until the motor failed on June 11, 1960 and was replaced with a new 1/3 HP motor and at this time the carbon vanes were replaced with new ones, which were never as satisfactory as the original set in the compressor. On January 23, 1961 the Gast compressor was replaced entirely by a Binks Model CP 1/3A compressor, rated at 4.6 cfm free air, having a 1/3 HP 1750 RPM electric motor drive. It was a twin piston 2-cylinder compressor integrally connected and driven. This compressor was used until the end of the project.

Compressed air was metered from August, 1959 to Jan. 14, 1961 by passing it through an orifice which created a differential that was measured by a Barton meter, recording air flow on 72-hr. circular charts. A great deal of trouble was experienced with frozen air lines during cold weather due to moisture condensation in the air lines, and in the orifice and flow sensing parts of the meter. On Jan. 14, 1961 the recording meter and orifice plate installation was replaced with a positive displacement gas meter which recorded the air flow on the suction side of the air compressor. This equipment has given excellent service from the maintenance point of view. It was necessary to calibrate the meter before it was installed at the pilot plant.

The amount of air applied to the process and the electrical energy used in compressing this air are shown in Table No. 14. The electrical energy was continuously metered and recorded daily. Table No. 19 gives specifications of the four types of compressors used and compares the efficiency of each to produce air per unit of electrical energy utilized. The Speedaire compressor was not suited to this kind of air compression tank as the air was compressed, stored then wasted to the process from the high pressure tank. This caused an excess usage of energy. A comparison of the other compressors shows that energy used varied from 2.22 to 3.98 KWH per 1,000 cu. ft. of free air delivered. The rate of delivery of air during the study period of this plant was varied considerably as shown by the tabulation in the last column of Table No. 19 and in Table No. 14.

Sampling Procedure and Methods

Most of the results of laboratory tests on the operation of this plant come from grab samples. All samples have been taken at three points in the plant. Raw sewage samples are collected at the discharge side of the volumetric feeder, just before the sewage enters the primary settling tank. Primary tank effluent samples are collected from the discharge pipe of the primary tank where the entire flow from the unit is sampled without disturbing the flow. It is obvious that this provides an excellent sampling position. See Figure No. 21 for details. Final tank effluent samples are collected from the discharge pipe located in the sampling box at the effluent end of the aeration tank. This installation is identical to the installation for primary effluent sampling.

Samples for BOD, suspended solids and coliform MPN have been taken three times per week throughout the period of investigation. Other tests have been taken at less frequent intervals and are reported in the various tables attached. During several months, Monday, Wednesday, and Friday samples have been taken, then for a change Tuesday, Thursday, and Saturday samples were collected. Grab samples have usually been taken between the hours of 9: 00 A. M. and 1: 00 P. M.

During the early months of operation of the project a study extending over three months was made comparing the suspended solids strength of raw sewage, as measured by grab and by composited samples. Composited samples were collected by means of a Sigma motor pump which took suction at the discharge side of the volumetric sewage feeder mechanism. The results of this study showed the composited sample to have slightly more suspended solids than the grab samples. There were a couple of mechanical features of this sampling method which were quite unsatisfactory so it was abandoned. A second sampler attached to the Roto-Dip feeder mechanism collected a small portion of sample each time the feeder rotated, 2,600 times per day, and placed the sample in a pipeline which led to a carboy in a refrigerator. We experienced many difficulties with this system too. The sampler was excellent but the line conveying the sample to the refrigerator plugged with solids several times and also gave other troubles. This latter sampler was used for composited, refrigerated samples from July 4, 1960 to June 1961. Both BOD and suspended solids determinations were run on the composited and grab raw sewage samples. The results, contrary to the previous study, indicated that the composited samples were weaker than the grab samples which we have used in this report.

It was decided at the outset of the first project in this study that grab samples would be adequate for this investigation. In view of this decision the installation of the experimental plant was laid out in such a manner that it was extremely difficult to design a satisfactory sampler for compositing raw sewage flow. Our experience with the sampling device leads us to conclude that a sampler must have a large diameter short length conductor leading the small portions of the sample to the compositing container which is located in the refrigerator. These precautions would prevent clogging with solids and the development of a slime coating on the inside of the conductor which would function as a treatment device as does the slime on the media of a trickling filter. The conductor must be of such a size that it can be easily cleaned daily. It has been concluded that probably the grab raw sewage samples have reported average strength somewhat larger than they should have because of the time of collection of grab samples. It was felt that primary and aeration tank effluents were quite uniform in quality and therefore less subject to hourly variation in strength. It is quite possible that the data showing per cent removal of BOD and suspended solids in the whole plant are somewhat high. There is no reason to doubt the results obtained relative to the strength of the effluent of the primary tank or the settling tank following the aerator.

Most of the tests, which are not routine, were run from samples collected on the regular sample days; however, some were not. This was done to level off the laboratory work load handled on any one day.

Laboratory Methods

All laboratory procedures have followed strictly the requirements set forth in "Standard Methods for the Examination of Water, Sewage and Industrial Wastes" 10th Edition, 1955.

BOD has always been set up on the same day of sampling, usually within an hour or so of sampling. Incubation has been in a 20° C refrigerator-incubator where complete darkness maintains. Standard 300 ml BOD bottles were used with glass water seal. The dissolved oxygen determination was run using the Winkler test until December 19, 1959 when it was indicated that there was interference and the results appeared somewhat erratic. We immediately changed to the Alsterberg (Azide) modification and have used it since that date on all dissolved oxygen determinations. Dilution water is made up and stored according to "Standard Methods" recommended procedures.

Suspended solids tests were run on all three plant components as well as the contents of the aeration tank. As large a sample as possible was selected to filter through the prepared Gooch crucible.

The test for most probable number of coliforms (MPN) was run on a presumptive basis only. In all respects it conforms to requirements of "Standard Methods". Decimal dilutions were prepared in sterile glassware, inoculated into lactose broth Durham fermentation tubes and reported + or - after 24 hours incubation at 35°C.

Settleable solids tests on mixed liquor of the aeration tank were run using 1,000 ml graduated cylinders. This test was usually run at the pilot plant site and results reported as shown in Table No. 5.

Volatile suspended solids were run, by igniting the crucibles at low red heat in a muffle furnace, after determination of suspended solids. All crucibles to be used for this determination were ignited before being used for the suspended solids determination.

Dissolved oxygen of samples from the three sampling points was determined in the field. The same method of running this test was used as was used for dissolved oxygen determinations in the BOD test.

Hydrogen ion concentration was measured by electrical pH meter and reported in Table No. 9.

Nine attempts were made to calculate the deoxygenation rate constant for the effluent from the aerator and one determination was made on the raw sewage to determine its rate of deoxygenation. Some of the determinations were carried for 5 days, some for 10 and two were carried for 26 days or more. In all cases the curves tend to be concave upward when plotted as shown on Figure No. 17. In order for it to be possible for one to compute the deoxygenation rate constant these curves must

be concave downward. The trend of these curves may be followed by studying Figure No. 17 or noting the information contained in Table No. 10. This determination is the evaluation of k using base "e" logarithms by running BOD's over 5-day periods. This is the constant k in the formula $y = L_a (1 - e^{-kt})$ which is the usual form of presenting the equation of the deoxygenation or BOD curve.

Sludge volume index is computed from the suspended solids and settleable solids determinations on the mixed liquor of the aeration tank. Results are reported in Table No. 11.

The test for nitrogen was run by the Kjeldahl method and reported as NO_2 in Table No. 12.

Chemical oxygen demand (COD) and the corresponding BOD determinations were made on certain designated samples that are reported in Table No. 17. The dichromate reflux method of the 10th Edition of Standard Methods has been used to conduct the test. COD values are recorded without applying the chloride correction. Further analysis of the BOD-COD relationship is given on Figure No. 20.

Operational Experience

Sewage feeding and measuring equipment has operated in an outstanding manner. Accuracy of flow and continuity of operation has been exceptionally well controlled by the Roto-Dip liquid feeder.

Air compression and air metering equipment has required considerable maintenance as one would expect from 24-hour daily operation. Air filters on the compressors have had to be cleaned at regular intervals. Most of the compressors, which we were able to purchase, were designed for a different type of service than for which we were using them. It has been necessary for us to replace motors, worn out vanes and parts of compressors for several types of compressors. The original air metering equipment involved passing the air flow through an orifice and utilizing a meter to integrate the differential created to give air flow to the aeration tank. The air handling facilities were exposed to the elements, expecially temperature, therefore, we had considerable trouble with condensation freezing in the small air lines, between the compressors and the aeration tanks. Condensation collecting on the orifice and in the meter sensing device gave considerable difficulty when freezing temperatures prevailed.

The strength of the raw sewage, as measured by BOD and suspended solids, has varied considerably, principally because of runoff following periods of rainfall. Source of the sewage is from a combined interceptor sewer and at times the sewage is diluted with runoff.

Best plant performance is associated with periods of operation when the sludge volume index (SVI) is relatively low. Many times during the operation of this

plant the sludge in the final settling tank would rise to the tank surface because of bulking conditions and would pass out with the plant effluent and would of course affect the per cent efficiency of the operation. It is to be expected that all solids, stabilized in the aeration part of the process, must ultimately pass out with the effluent, because there is no place to store them or no established way to return them to the primary process. We developed an air lift pump and operated it several times to return varying amounts of mixed liquor from the aeration tank to the primary tank, hopeful that this would remove some of the bulking solids from the aeration part of the plant and lower the sludge blanket in the settling compartment of the aerator so it would not discharge solids with the effluent from the plant. This air lift pump was operated once during each month, July through November 1960 and for four of the five times it was quite successful in causing the sludge blanket, in the aeration settling compartment, to lower to a place where it did not discharge large amounts of solids with the effluent. During one of the return tests power to the plant was interrupted and the results were obscured by this fact. The blanket was successfully lowered but reason for the lowering was not clear.

During those periods when the secondary treatment process was throwing off solids the effluent was not as clear as normal because suspended solids were present, but throughout this operation we noted that there was not a proportionate increase in the BOD of the final effluent, indicating that at least part of these solids had been stabilized by the treatment process. There were some times when the aeration tank completely lost all its settleable solids or the solids were so bulky that they occupied the full test cylinder during the settleable solids test determination. After such a period the tank would have to develop a new effective activated sludge floc. The reason for the loss of the activated sludge was obscure and would be an excellent problem to study in any similar installations.

Quite a bit of foaming was present on the surface of the aeration tank early in the breaking-in-period and it returned whenever the settleable solids content of the mixed liquor was low. January 25, 1961 was the worst sudsy foaming condition noted for this plant. At this time a white sudsy foam accumulated to several inches depth and covered the aerator, settling compartment and had even spilled over into the sampling box. This foam is a white sudsy type of foam which disappeared when the solids content of the mixed liquor increased to a reasonable value. Trend of the settleable solids content of the mixed liquor is given in Table No. 5.

The treatment tanks were fabricated of thin reinforced concrete and were constructed underground with an earth cover of 12 to 18 inches, each tank having two or three access manholes. Air lines and metering equipment were housed in unheated shelters and were subject to freezing temperatures for several cold winter months. As a result we experienced a great deal of difficulty with frozen condensation in the small air lines and around the orifice plates which created the differential which operated the air flow recorders. This operating difficulty was completely eliminated by the installation of positive displacement gas meters to measure and record the flow of air to the aerator.

The research plant was completely inactive for a 44 consecutive day period in December, January and February 1959 and 1960 due to a double failure in the underground power cables which had to be located and repaired. During this period of cold weather no sewage or air was applied to the plant. While we felt this was an unfortunate situation it did have its good features because this provided a test of what happens when those using the facilities "take an extended Florida trip". Plant operation was renewed February 11 and the rest of the month the plant produced excellent results, in fact the February results were the best of any month of record. The activated sludge didn't seem to suffer any serious effects from the functional point of view. There has been no discernable clogging of aerator tube due to this shutdown period. From all noticable points of view the rest period helped rather than hampered plant efficiency.

The plant discussed in this report represents one of three different types of small plants involving different unit treatment processes which were operated concurrently. One of the other plants was operated as a control, involving the same size tanks as this plant and handling the same rate of flow of the same sewage but utilizing a horizontal flow primary tank. Flow line diagram for the control plant was never changed as it was for the plant of this report when the primary plant was bypassed during the last six months of operation.

Discussion of Results

The results of laboratory analyses, field data and statistical interpretation of these data are presented in tabular form as follows:

Table No. 1 BOD Loading and Removal

Table No. 2 Suspended Solids Loading and Removal

Table No. 3 Coliform Population

Table No. 4 Effect of Treatment Processes on Number of Coliforms

Table No. 5 Settleable Solids in Mixed Liquor

Table No. 6 Suspended, Volatile and Fixed Solids

Table No. 7 Monthly Average Values of Suspended, Volatile and Fixed Solids in Plant Samples

Table No. 8 Dissolved Oxygen Concentration

Table No. 9 Hydrogen Ion Concentration - pH

Table No. 10 Deoxygenation Rate Constant - k

Table No. 11 Sludge Volume Index (SVI) and Suspended Solids of Mixed Liquor

Table No. 12 Nitrogen Content of Plant Effluent

Table No. 13 Volumetric Sewage Flow Rate Through Plant

Table No. 14 Plant Operational Characteristics

Table No. 15 Statistical Summary of Operating Characteristics as Measured by BOD, Suspended and Volatile Solids

Table No. 16 Accumulated Sludge Depths

Table No. 17 Chemical Oxygen Demand (COD)

Table No. 18 BOD and Suspended Solids Loading and Removal

Table No. 19 Compressed Air Factors

In addition to the preceding list of tables, considerable data are persented in drawings and charts as follows:

Fig. No. 1 through Fig. No. 8 BOD Removal

Fig. No. 9 through Fig. No. 16 Suspended Solids Removal

Fig. No. 17 Trend of the BOD Curves

Fig. No. 18 BOD and Suspended Solids Loading and Removal

Fig. No. 19 Plant Operating Characteristics

Fig. No. 20 COD - BOD Correlation

Fig. No. 21 Plant Details

It will be convenient to divide the period of plant operation into two phases when discussing the results of operation. Phase one will be the period extending from August 1959 through December 1960 when the plant was operated as a two stage plant involving a primary sedimentation, solids-contact unit followed by a secondary aeration-sedimentation unit. Phase two will be the period extending from January 1961 through June 1961 the time when the primary unit of phase one was bypassed. Phase one is 16 months long, phase two, 6 months.

Table No. 1 presents statistical information about mean monthly BOD of the plant components. Plant influent BOD for both phases of operation are very nearly alike at 166 and 165 mg/l. Plant effluent BOD's are 16 and 14 mg/l for phase one and two respectively. Seven of the 16 months of operation in phase one had effluent BOD's of 10 or less and four of the 6 months of phase two had BOD's of 10 or less. Primary effluent of phase one contained 88 mg/l of BOD, with 46 per cent removal in the primary stage of the plant. Phase one operation produced an effluent having 90 percent removal while phase two effluent had 91 per cent removal of BOD. While both removals are considered excellent it is especially important to note how efficient the process actually was as operated under phase two conditions. Reference to Table No. 13 shows that the volumetric flow during phase two was 85 per cent of the flow rate during phase one. Information from Table No. 14 shows that more air was used during the second phase of the study. Both plant effluents are as good as produced by most municipal plants which dilute their plant effluents into the surface waters of the vicinity.

The results of removal of suspended solids from the sewage are given in Table No. 2. The suspended solids concentration of the plant influent during phase one averaged 191 mg/l while during phase two it averaged 134 mg/l which is due principally to the high runoff during the wet spring months of phase two of the study. Primary effluent of phase one contained 47 mg/l of suspended solids and the aerator effluent averaged 16 mg/l giving an overall plant removal of 92 per cent, which is considered excellent. During 7 of the 16 months of phase one operation the plant effluent contained 10 or less mg/l of suspended solids. During phase two the single unit produced an effluent that was essentially as good as during phase one. The 17 mg/l of suspended solids in the effluent represented a removal of 87 per cent. The plant effluent contained less than 10 mg/l of suspended solids during only one month of phase two operation. The results of the BOD and suspended solids removal by the phase two operation are so pleasantly surprising that it is considered essential that this phase of the study be pursued farther to find out what refinements of this type of operation might improve this general plan of treatment. Control of the periodic throwing off of solids with the effluent from both phase one and two would definitely improve the effluent from these plants. Again it is to be noted that the small pilot plant was able to remove suspended solids as effectively as most municipal plants. Barring the periods when the plant is discharging solids the effluent is clear, sparkling and odorless. In most cases it would have much less turbidity than local streams.

Table No. 3 presents data on MPN for the research pilot plant and for the Columbus Sewage Works as well as the Brookside Sewage Works. The Columbus plant is an activated sludge plant designed for 120 million gallons per day capacity. The Brookside plant is an aerobic digestion plant serving a small subdivision and a country club. MPN's for these two outside plants are given for comparative purposes. The individual samples, reported in Table No. 3, show the number of coliforms per 100 ml in the raw sewage, the primary effluent and the plant effluent. Samples are arranged chronologically.

Table No. 4 condenses and interprets the averaged monthly MPN data of Table No. 3 for both phases of operation. Average removal during phase one was 82.4 per cent in the whole plant while it was 97.7 during phase two. Secondary removal in phase one operation is more efficient than primary removal. In fact there were two months when there were more coliform in the primary effluent than in the influent. There were four months during phase one operation when overall removal was less than 92 per cent. It is important to note that in both cases the plant effluent contains between 2.6×10^5 and 1.2×10^6 coliform organisms per 100 ml. This concentration is high enough so the effluent must be considered potentially dangerous from the public health point of view. It is very interesting to note that phase two operation is quite a bit more efficient in removing coliform than is phase one type of operation. This is of real significance because it represents less treatment time than is employed in phase one operation. This is another reason why phase two type operation should be studied further to develop it to its most efficient limits.

There is little reason to expect that any reasonable change in the operational procedure, loading, detention, etc. will ever reduce the number of coliforms below 1,000 per 100 ml. Disinfection of plant effluent would be required to bring about this change. A simple, accurate and foolproof chlorinator, used to disinfect the effluent of these small plants would be a great boon to the public health field for it would render the effluent from these small plants harmless from the standpoint of transmission of disease.

In Table No. 5 is presented data on the settleable solids content of the mixed liquor of the aeration tank. The information in this table and in Table No. 11 on the sludge volume index are definitely related. The simple test for settleable solids is an excellent parameter of secondary plant performance. It indicates the condition of the mixed liquor and its capacity to remove organic matter discharged by the primary process. Sludge volume index is even a better parameter of plant performance. The lowest percentage removal of BOD and suspended solids shown on Figure No. 19 occurred during December 1960 after the SVI reached an unreasonably high value during the latter part of November. Practically all of the activated sludge was lost from the aerator during December 1960. Settleable solids was generally higher during phase two type of operation than during the previous type of operation. This would be expected as all the solids in the raw sewage were discharged into the aeration tank while they had previously been removed by the primary tank. There were times when it was rather difficult to determine settleable solids of the mixed liquor as the solids were so evenly dispersed in the mixed liquor that they would hardly settle. As a result of this condition it was hard to say whether there were 900+ ml/l or a figure approaching 0 ml/l.

When the settleable solids are extremely low, and there is a poor activated sludge developed, the effluent of the secondary settling tank will be poor in removal of suspended solids and BOD. When the settleable solids exceed about 200 ml/l and are less than 800 ml/l the final settling tank is usually able to provide an excel-

lent effluent. When the settleable solids exceed about 800 ml/l we find a bulking sludge condition that drives solids out of the final settling tank because they cannot be separated from the liquid effluent. Apparently this type of secondary settling tank, having upward flow through a sludge blanket, is able to operate with a more bulky sludge than is conventional secondary settling tanks at municipal plants. This is borne out by the fact that much of the time this plant had a high sludge volume index and still turned out an excellent effluent.

The fixed and volatile components of suspended solids are presented in the information given in Tables No. 6 and No. 7. Table No. 6 presents the more or less irregularly collected results which were secured during the first 5-months of operation. During the remaining 17 months of operation volatile and fixed solids were usually run whenever suspended solids were. Information collected on these tests, starting with February 1960, is given in Table No. 7 and further analyzed in Table No. 15. Note that volatile solids are a high percentage of suspended solids in all three plant components. Averages have been computed and given for both phases of treatment and for all plant components. The percentage removal of suspended, volatile and fixed solids by the two phases of operation are very much alike, the second phase type operation being somewhat less efficient than the first phase; however, both phases were quite satisfactory in their ability to remove these solids.

Table No. 8 presents data relative to dissolved oxygen in the plant components. There always has been dissolved oxygen in the plant effluent. Usually the raw sewage has a small amount of oxygen but not always. The primary effluent is always septic. Noteespecially that the dissolved oxygen in the aerator effluent is especially high during phase two operation when a rather large amount of air was being applied to the aerator when compared with previous level of application. Note Figure No. 19 and Table No. 14 to see the variation in the amount of air applied to the process. A December 19, 1959 sample of plant effluent was treated with 0.4 ml of methylene blue, as recommended in the relative stability test, and this sample did not lose its blue color in a period of 75 days, indicating that there was still dissolved oxygen in it and that the effluent was a relatively stable one.

Hydrogen ion concentration in the three plant components is given in Table No. 9. There is little change in pH as the sewage passes through this plant. Average values in the table indicate a reduction from 7.4 to 7.2 in the primary tank with no change as it passes through secondary treatment.

Information about the character of the deoxygenation curve for the raw sewage and for the plant effluent is given in Table No. 10. It was not possible to compute the deoxygenation constant because of the character of the daily BOD values. As already discussed the curves are concave upward and must be concave downward if the deoxygenation constant is to be evaluated. We are unable to state why the BOD curve takes the form which it does in these studies. Several times the 5-day BOD is relatively low and comes close to following theoretically ideal trends but at the end of the 6th or 7th day it starts off with an increased rate of demand for oxygen. Possibly this is the second or nitrogenous stage of deoxygenation but we are only able to surmise that it is.

Variations in the sludge volume index (SVI) and the suspended solids in the mixed liquor of the aeration tank are given in Table No. 11 part of which has been discussed previously. Prior to November 1959 it was useless to attempt to run the SVI with the per cent removal of BOD and suspended solids, as shown on Figure No. 19, indicates that plant performance was good to excellent during the early months of 1960 but when the SVI became large late in November, that plant performance fell markedly during December and a poor quality mixed liquor was present. It is quite noticeable that the plant, under conditions of phase one operation, was able to support less suspended solids in the aeration tank than it was under phase two type of operation. The suspended solids content of the aeration tank is much higher during the last six months of operation, than at any other time during the study. Recall that during this same period there was a much greater amount of air furnished to the plant than had previously been provided. During the phase two type of operation the SVI appears to be much more of the same order that is expected at municipal plants for a satisfactory type of mixed liquor.

Theoretical volumetric rate of flow of sewage through the pilot plant is shown in Table No. 13 along with the corresponding times of detention in the various parts of the plant. During the first phase of operation, from August 1959 through December 1960, average flow was 895 gallons per each 24 hours with 25.8 hours detention in the primary tank, 14.8 hours in the aerator and 5.0 hours in the final settling compartment. During the second phase of operation, involving the last six months of operation, flow rate averaged 764 gallons per day with 17.6 hours detention in the aerator and 5.9 hours in the final settling compartment. Phase one type of treatment provided 45.3 hours detention, which is nearly twice as much as the 23.5 hours provided under phase two. For these relative periods of detention, and considering the increased amount of air used, it is of considerable importance to note the plant performance during phase two by studying Figure No. 19 and Tables No. 1, No. 2 and No. 14. Allowing 100 gal. per capita per day flow, phase one provides for 9 persons and phase two just less than 8 persons. Assuming that the average per capita raw BOD per day is 0.17 lbs., phase one is providing for 7 persons while phase two is caring for 6 persons. If garbage were being disposed of in these tanks the latter figures would have to be halved if it were assumed that garbage would contribute about the same BOD as does domestic sewage.

Table No. 14 supplies information on several facets of overall plant performance. Average values are given for the 16 months of phase one operation and the 6 months of phase two operation. Raw sewage BOD for the two periods averaged the same for all practical purposes at 165 mg/l with essentially the same overall plant removal at 90 or 91 per cent. Phase two provided the better removal based on percentage, considering the fact that the plant flow was less, the total treatment time less and the air provided more during phase two operation than during phase one operation. The information given in Tables No. 14, No. 18 and Figure No. 18 are significant at this point of thought. From column 5 figures of Table No. 14 we note that phase one treatment removed 1.119 lbs. of BOD per day and that phase two operation

removed an average of 0.986 lbs. per day. These two loads expressed as lbs. removed per day per 1000 gal. tank capacity give 0.660 and 1.34 respectively, indicating that phase two type of operation is nearly twice as efficient as phase one. Again this conclusion neglects consideration of the amount of air being used or the rate of volumetric flow through the plant units. It is important to note that the second phase of operation is twice as efficient of its use of tank volume in removing BOD than is phase one type of operation. Phase one and two operations used 6 and 10 KWH per day of energy respectively. At 3 cents per KWH this amounts to 18 and 30 cents per day operating expenses for these two plants. In this respect phase one is much more desirable than phase two type operation. It is quite possilbe that phase two type operation was not able to utilize all the air being provided to the system. Reduced air usage for the second phase type operation should be further studied to see if it can be reduced and still provide a high degree of removal of BOD. It is important to note that air provided to the plant averaged 1,336 and 4,824 cu. ft. per lb. of BOD loading to the plant respectively for phase one and two, also that 1.79 and 5.80 cu. ft. of free air per gal. of sewage was provided to these two phases of treatment. In an effort to increase the air applied to the plant during the months of November and December 1959 an economically unfavorable arrangement of air compressors was used.

BOD, suspended and volatile solids results have been summarized in Table No. 15 for the entire period of study. Data for the individual tests were grouped into class intervals and statistical parameters evaluated and presented in tabular form for comparative purposes. Arithmetic mean, standard deviation, 95 % confidence limit of the mean, and range of the samples are shown for the raw sewage, primary effluent and plant effluent for both phases one and two type of operation. Some data was omitted from the tabulation prior to summarizing because it was extreme and and unsatisfactory for some reason. The samples representing raw and primary effluent BOD, suspended solids and volatile solids formed distributions which were near normal distributions; however, the aeration tank effluent formed distributions for the three types of tests that were skewed with modal values near the low end of the curve. Both phases of operation followed this same shape of distribution.

Accumulated sludge depths in the primary solids contact tank are given in Table No. 16. After the first 16 months of operation the depth had accumulated to approximately 16 inches over the entire tank length. The last depth recording is the depth after the tank had sat idle for a 6-month period and shows a little over one inch compaction, resulting in a final depth of near 15 inches fairly well distributed over the entire tank bottom.

Since the middle of May, 1960 chemical oxygen demand (COD) tests have been run on the three plant components for comparison with BOD's and for general information gained from the test itself. The dichromate reflux method of the 10th Edition of Standard Methods has been used to conduct the test. The correction for chloride content was not made. Average chloride content is near 70 mg/l thus the COD's should have been reduced by 23 % of 70 or by 16 mg/l. COD data is presented in Table No. 17 and further summarized on Figure No. 20. The correlation between

BOD and COD for the three plant components for both phases of operation is shown on Figure No. 20. It appears that generally the COD increases as the BOD increases but as the BOD approaches zero the uncorrected COD has a significant value near 30 mg/l. The data was separated for each of the three plant components and for the plant effluent operating under phase two type operation and a straight line of best fit was computed by the least squares method and plotted on Figure No. 20. The corresponding formula of each correlation curve and the composit curve for all samples are given along each line on the figure. These formulas are in the straight line intercept form, $y = mx + b$, where y = COD, m is slope, x is BOD and b is the y-intercept of the straight line. Primary, secondary and overall plant removals of COD are 58%, 50%, and 79% for phase one type of operation while phase two type of operation provides 77% overall removal of COD.

Average monthly data for loading and removal of BOD and suspended solids have been tabulated in Table No. 18. In order to prepare the loading and removal curves of Figure No. 18 it was desirable to present this data on the basis of unit tank volume. Presented in this manner it should be possible, with proper allowances for volumes and strengths, to transpose this information to other size tanks. The tabular values are lbs. of BOD or suspended solids per day per 1,000 gal. tank capacity and represent the average of the daily values for each month indicated. The overall averages for the table are of considerable importance. Note that there is about four times as much suspended solids removed in the primary tanks as in the secondary tanks per 1,000 gal. tank capacity while the BOD removal in the primary and secondary processes is approximately the same for phase one type of operation. Primary settling is more efficient than secondary treatment for the removal of suspended solids and conversely secondary treatment is more efficient than primary settling in removing BOD. This last statement is borne out by the fact that the primary settling tank removes 75.5% of suspended solids coming to it while the secondary removes 83.1% of its BOD load. Overall plant BOD and suspended solids removals are 90% and 92% for the phase one type of operation. Phase two type operation shows 91% and 87% removals of BOD and suspended solids respectively. While all the removals are excellent, phase two type operation is more efficient in BOD removal and conversely phase one type operation is more efficient in suspended solids removal.

Four types of small air compressors were used during the 22 months of study reported and the operating characteristics of each are summarized in Table No. 19.

Summary, Conclusions, and Recommendations

1. BOD of the plant effluent was 10 mg/l or less for seven of the first sixteen months of operation during which time it averaged 16mg/l. For phase two type of operation, involving 6 months of operation, plant effluent BOD was 10mg/l or less during four of the six months and averaged 14 mg/l for the period. The main deterrent to producing a better effluent is the periodic unloading of suspended solids

and its corresponding BOD load, with the secondary effluent. The phase two type of operation showed less tendency to throw off solids with the aerator effluent than had been experienced earlier with phase one type of operation.

2. Suspended solids concentration in the plant effluent has been 10 mg/l or less during seven of the first 16 months of operation averaging 16 mg/l for the same period of record. During the last six months of operation only one month showed less than 10 mg/l of suspended solids in the effluent; however, average suspended solids for the six months was 17 mg/l. During phase one of the plant operation the activated sludge frequently became bulky and discharged solids with the plant effluent. During these periods the BOD and suspended solids removal are both below what the process is capable of producing if bulking solids could be controlled. A method of regulating this phenomenon is required before this process can be relied on to meets its peak performance. Inherent to this type of plant is the fact that the secondary part of the plant has no way of storing solids beyond a certain limit. It must therefore discharge them with the liquid effluent. During the 6-month phase two type of operation less solids unloading was noticed at the plant; however, we hasten to note that continued operation of the plant in this manner would probably bring about the time when the plant would be forced to unload its solids.

3. We have concluded from these studies that no reasonable detention period or amount of aeration will reduce MPN of coliforms to less than 1,000 per 100 ml regularly and, therefore, if it is desired that the coliform count be kept at a very low level the effluent must be chlorinated. A very real contribution could be made at this point by the manufacturers by providing simple, inexpensive and sturdy equipment for the addition of chlorine compounds to the plant effluent for the purpose of rendering the effluent safe for disposal in the surface waters of a community. Generally speaking, the BOD and suspended solids content of the effluent are satisfactory for disposal in very small streams; however, the very real threat of disease transmission is always present if the plant effluent is not adequately chlorinated, the same as it is with municipal plants discharging effluents into small streams.

4. In connection with establishing capacity required in the primary settling tank or solids contact tank and in the aeration tank, per unit of volumetric and organic loading we present Figure No. 18 and Table No. 18. During phase one type of operation when primary detention was 25.8 hours the primary process was able to remove daily 1,116 lbs. of suspended solids and 0.608 lbs. of BOD per 1,000 gal. of tank capacity. The secondary part of the plant was able to remove 0.312 lbs. of suspended solids and 0.726 lbs. of BOD daily per each 1,000 gal. of combined tank capacity when the detention in the aerator was 14.8 hours and in the final settling tank it was 5.0 hours. During phase two type of operation the aeration compartment and its settling tank was able to remove 1,019 lbs. of suspended solids and 1,339 lbs. of BOD daily per 1,000 gal. of combined tank capacity when the detention in the aeration tank was 17.6 hours and in the settling tank it was 5.9 hours.

5. An average of approximately 1,336 cu. ft. of free air was applied per lb. of BOD coming to the plant and approximately 1,500 cu. ft. of air per lb. of BOD

removed during phase one type of operation. A great deal more air was used during phase two type of operation when 4,824 cu. ft. of air was applied per lb. of BOD coming to the plant and 5,293 cu. ft. was applied per lb. of BOD removed. During phase one 1.48 cu. ft. of air per gal. of sewage was applied and during phase two 5.80 cu. ft. per gal. was applied.

6. Close to 16 inches of sludge depth accumulated in the first 16 months of operation. During 6 months of non-use of the primary settling tank the sludge consolidated about 1 inch to a depth of 15 inches.

7. Air compression is probably the single most important item in the successful operation of this plant once the physical plant size has been determined. Our limited experience with several types of air compressors leads us to recommend that they should be designed for continuous service with motors which are sized conservatively for this kind of service. Generally speaking they should run as slowly as possible to avoid wear and excessive noise. These compressors should be designed for delivery of the specified amount of free air at the relatively low pressure required at the installation. This pressure will usually be only a few lbs. per sq. inch. There was considerable difference in the ability of different compressors to deliver air, expressed in KWH used per 1,000 cu. ft. of air delivered. The best performing compressors used slightly more than 2.2 KWH of electrical energy per 1,000 cu. ft. of air delivered. One of the compressors, used on another study, was more efficient than any used on this plant. During phase one type of operation it took 6 KWH per day and during phase two type of operation it took 10 KWH per day.

8. The plant produced some rather surprisingly fine removals during the period when it was operated as an aeration tank only, or what we have chosen to call phase two type of operation. We have collected only 6-months of data on this type of operation and have not made a variation in the method or amount of air that has been applied. We recommend that this type of plant operation and several of its variations should be studied further.

Facets of the Study which Need to be Investigated Further.

1. The problem of adequate sewage disposal is of such significance to the health of a great segment of our population, forced to use small disposal plants, that the study needs to be continued in a manner similar to its past operation so that the effects of the seasons, weather, and reduction in tank capacity due to accumulated solids may be studied and evaluated. Results of these studies suggest that it might be possible to eliminate tile disposal fields as part of small plant treatment units.

2. There were so many excellent results received from the short operation of the plant without primary settling preceding aeration that this type of operation should be studied further. It would be anticipated that this type of operation would soon produce an effluent that would of necessity have to throw off solids as they cannot accumulate too long in the aerator so it is suggested that the flow line of the plant be

changed to provide aeration first for 18 to 24 hours followed by settling for another 24. This would mean the complete reversal of the plant as operated during the first 16 months of the study. The longer final settling period should provide a retention that would remove the solids in the aerator effluent and solids storage from the process would take place in secondary settling. Refinements of air usage should be studied in connection with this type of operation.

3. Variations of the volumetric rate of sewage flow should be studied. Two ways seem logical for doing this. One is to apply the present volume of sewage flow over a shorter part of the day, say 16 hours, and not apply flow during the rest of the day. Another is to continue to apply the flow uniformly but change the rate either up or down from the present level.

4. The disposal of ground garbage in these units would certainly be of interest to the profession.

5. A method needs to be developed to prevent or otherwise control the aerobic process from discharging solids with the liquid effluent. Obviously this process must discharge solids, otherwise the aerator will become clogged with an accumulation of sludge. One method which shows promise is to return mixed liquor to the primary influent for a short period of each day so as not to disrupt the desired solids concentration in the mixed liquor. A second method is to install the aerator ahead of a larger settling tank which would have a surface loading rate that would retain the discharged solids from the aeration process.

6. A satisfactory method of compositing and refrigerating raw sewage samples must be developed for this installation. This can be done by giving proper attention to the plant layout, provided funds are available.

7. Studies should be initiated to determine the relative sizes of primary settling, aeration and secondary settling units. It is quite probable that a larger secondary settling unit would be helpful in producing a better plant effluent.

B.O.D. REMOVAL

Table No. 1 gives the results of operation of the U.S. Public Health Service plant for the 22-month period from August 1959 through June 1961, insofar as BOD loading and removal is concerned.

TABLE NO. 1 BOD LOADING and REMOVAL*

Month and Year	Plant Loading mg/l			Per Cent Removal	
	Raw	Primary Effl.	Final Effl.	R-P (a)	R-F (b)
Aug., 1959	156	97	25	38	84
Sept., 1959	154	108	26	29	82
Oct., 1959	127	99	15	22	88
Nov., 1959	122	102	18	16	85
Dec., 1959	118	72	18	39	85
Feb., 1960(c)	126	46	22	63	83
Mar., 1960	173	62	7	64	96
Apr., 1960	154	66	9	57	94
May, 1960	142	75	17	47	88
June, 1960	153	87	8	43	95
July, 1960	175	110	8	37	95
Aug., 1960	198	98	3	51	97
Sept., 1960	224	90	10	60	96
Oct., 1960	202	91	8	55	96
Nov., 1960	213	92	11	57	95
Dec., 1960	224	108	45	52	80
Aug., 1959 - Dec., 1960 Average	166	88	16	46	90
Jan., 1961	230		30		87
Feb., 1961	188		9		95
Mar., 1961	95		10		89
Apr., 1961	132		10		92
May, 1961	156		17		89
June, 1961	191		9		95
Jan., 1961 - June, 1961 Average	165		14		91

*BOD = 5-day 20°C Biochemical Oxygen Demand

(a) R-P indicates removal in the primary settling tank.

(b) R-F indicates removal by the whole plant.

(c) The plant was not operating during January 1960 due to power line failure.

SUSPENDED SOLIDS REMOVAL

Table No. 2 gives the results of operation of the U. S. Public Health Service plant for the 22-month period from August 1959 through June 1961, insofar as suspended solids loading and removal is concerned.

TABLE NO. 2 SUSPENDED SOLIDS LOADING and REMOVAL**

Month and Year	Plant Loading mg/l			Per Cent Removal	
	Raw	Primary Effl.	Final Eff.	R-P (a)	R-F (b)
Aug., 1959	246	30	32	88	87
Sept., 1959	187	45	26	75	85
Oct., 1959	202	45	28	78	86
Nov., 1959	140	43	21	69	85
Dec., 1959	137	35	8	74	94
Feb., 1960 (c)	136	30	13	78	90
Mar., 1960	166	37	9	78	95
Apr., 1960	159	34	6	79	96
May, 1960	170	34	6	80	96
June, 1960	174	43	9	75	95
July, 1960	204	79	13	61	94
Aug., 1960	217	112	10	48	95
Sept., 1960	230	63	6	73	97
Oct., 1960	228	41	11	82	95
Nov., 1960	192	30	11	84	94
Dec., 1960	266	44	45	83	83
Aug., 1959 - Dec., 1960 Average	191	47	16	75	92
Jan., 1961	168		33		80
Feb., 1961	154		14		91
Mar., 1961	118		4		97
Apr., 1961	74		14		81
May, 1961	148		24		84
June, 1961	139		13		91
Jan., 1961 - June, 1961 Average	134		17		87

**Suspended solids determined by the Gooch crucible method.

(a) R-P indicates removal in the primary settling tank.

(b) R-F indicates removal by the whole plant.

(c) Plant out of operation in Jan. 1960 due to power line failure.

TABLE NO. 3 COLIFORM POPULATION

Most Probable Number of Coliforms, MPN

In the following tabulation is given the MPN of coliforms per 100 ml. of sample. These samples represent the results from decimal dilutions in 5 similar tubes after 24 hr. incubation at 35°C in accordance with Standard Methods procedure. These are presumptive results, giving an estimation of coliform group density. Some samples of plant effluent and raw sewage are included from the Columbus and Brookside plants. Table No. 3 gives the MPN of coliform in individual samples of plant components throughout the operating period. Table No. 4 shows the average removal of coliform organisms by the sedimentation and aeration processes. Results are based on averages for each month of record and represent a summary of Table No. 3.

Date 1959	Sample Point*	MPN per 100 ml.**	Date 1959	Sample Point*	MPN per 100 ml.**
Aug. 6, 59	A	4.9×10^5	Oct. 13, 59	A	9.5×10^5
Aug. 8, 59	A	3.3×10^5	Oct. 15, 59	A	2.3×10^6
Aug. 11, 59	A	1.1×10^6	Oct. 17, 59	P	7.9×10^6
Aug. 13, 59	A	1.7×10^6	Oct. 17, 59	A	2.3×10^6
Aug. 15, 59	A	4.9×10^5	Oct. 20, 59	A	3.3×10^6
Aug. 15, 59	R	7.0×10^7	Oct. 22, 59	A	1.8×10^7
Aug. 18, 59	A	7.9×10^5	Oct. 24, 59	R	4.9×10^6
Aug 20, 59	A	7.9×10^6	Oct. 24, 59	A	7.0×10^6
Aug. 22, 59	A	2.3×10^6	Oct. 27, 59	A	2.3×10^6
Aug. 25, 59	R	4.9×10^7	Oct. 29, 59	A	7.9×10^6
Aug. 25, 59	A	3.3×10^6	Oct. 31, 59	A	7.9×10^4
Aug. 27, 59	A	3.3×10^6	Nov. 3, 59	A	2.3×10^6
Aug. 29, 59	A	9.5×10^4	Nov. 5, 59	A	1.1×10^6
Sept. 3, 59	A	7.9×10^5	Nov. 7, 59	A	2.2×10^6
Sept. 8, 59	A	2.3×10^6	Nov. 12, 59	A	2.3×10^6
Sept. 10, 59	A	4.9×10^6	Nov. 14, 59	P	4.9×10^6
Sept. 12, 59	A	2.3×10^6	Nov. 14, 59	A	1.3×10^6
Sept. 15, 59	A	7.9×10^5	Nov. 17, 59	A	3.3×10^5
Sept. 17, 59	A	4.9×10^6	Nov. 19, 59	A	1.3×10^6
Sept. 19, 59	A	4.9×10^6	Nov. 21, 59	R	1.8×10^6
Sept. 19, 59	R	7.0×10^7	Nov. 21, 59	A	7.9×10^4
Sept. 22, 59	A	7.9×10^4	Nov. 24, 59	A	2.2×10^5
Sept. 24, 59	R	3.3×10^7	Nov. 28, 59	P	1.7×10^6
Sept. 24, 59	A	2.2×10^5	Nov. 28, 59	A	1.7×10^5
Sept. 26, 59	A	3.3×10^5	Dec. 1, 59	A	4.6×10^5
Sept. 29, 59	A	2.8×10^6	Dec. 3, 59	A	1.7×10^5
Oct. 1, 59	A	1.1×10^5	Dec. 5, 59	A	2.3×10^5
Oct. 6, 59	A	1.3×10^6	Dec. 8, 59	A	7.9×10^4
Oct. 8, 59	A	2.3×10^5	Dec. 10, 59	A	4.9×10^5
Oct. 10, 59	A	3.3×10^5	Dec. 15, 59	A	4.9×10^5

TABLE NO. 3 CONTINUED

Date 1959 - 1960	Sample Point*	MPN per 100 ml. **
Dec. 17, 59	A	2.3×10^5
Dec. 19, 59	R	7.9×10^6
Dec. 19, 59	A	3.3×10^5
Dec. 22, 59	P	4.9×10^6
Dec. 22, 59	A	4.9×10^4
Dec. 24, 59	A	1.8×10^5
Dec. 26, 59	A	1.1×10^5
	1960	
Feb. 13, 60	R	1.1×10^6
Feb. 13, 60	P	7.9×10^5
Feb. 13, 60	A	4.9×10^5
Feb. 16, 60	A	2.3×10^6
Feb. 18, 60	R	7.9×10^6
Feb. 18, 60	P	4.9×10^6
Feb. 18, 60	A	1.7×10^5
Feb. 20, 60	A	2.3×10^6
Feb. 23, 60	A	4.9×10^4
Feb. 25, 60	A	4.9×10^6
Feb. 27, 60	R	4.9×10^6
Feb. 27, 60	P	1.7×10^6
Feb. 27, 60	A	7.9×10^5
Mar. 1, 60	A	2.2×10^5
Mar. 3, 60	P	4.6×10^6
Mar. 3, 60	A	1.3×10^5
Mar. 5, 60	A	4.9×10^4
Mar. 8, 60	A	2.3×10^5
Mar. 10, 60	R	7.9×10^6
Mar. 10, 60	P	1.7×10^6
Mar. 10, 60	A	1.7×10^5
Mar. 12, 60	A	4.9×10^4
Mar. 15, 60	A	7.8×10^3
Mar. 17, 60	A	4.9×10^4
Mar. 19, 60	A	3.3×10^4
Mar. 22, 60	A	1.3×10^5
Mar. 22, 60	R	4.9×10^6
Mar. 22, 60	P	1.1×10^6
Mar. 24, 60	A	1.4×10^4
Mar. 29, 60	A	7.9×10^5
Mar. 31, 60	A	2.3×10^6

Date 1960	Sample Point*	MPN per 100 ml. **
Apr. 2, 60	A	7.0×10^4
Apr. 5, 60	A	3.3×10^4
Apr. 7, 60	P	1.3×10^6
Apr. 7, 60	A	2.4×10^5
Apr. 7, 60	R	7.0×10^6
Apr. 9, 60	A	7.0×10^4
Apr. 12, 60	A	7.9×10^4
Apr. 14, 60	A	4.6×10^4
Apr. 16, 60	A	2.2×10^4
Apr. 19, 60	R	2.2×10^7
Apr. 19, 60	P	3.3×10^6
Apr. 19, 60	A	3.3×10^4
Apr. 21, 60	A	7.9×10^3
Apr. 23, 60	A	1.1×10^5
Apr. 26, 60	A	4.9×10^4
Apr. 28, 60	A	7.9×10^4
Apr. 30, 60	A	7.9×10^4
May 3, 60	A	7.9×10^5
May 5, 60	R	1.7×10^7
May 5, 60	P	1.7×10^7
May 5, 60	A	1.1×10^5
May 8, 60	A	3.3×10^4
May 10, 60	A	3.3×10^4
May 12, 60	A	3.3×10^4
May 14, 60	A	2.3×10^5
May 17, 60	R	1.3×10^7
May 17, 60	P	4.9×10^6
May 17, 60	A	2.8×10^5
May 19, 60	A	1.1×10^5
May 21, 60	A	7.9×10^4
May 28, 60	A	4.9×10^4
June 4, 60	P	3.5×10^6
June 4, 60	A	4.9×10^3
June 23, 60	R	4.9×10^6
July 4, 60	P	3.3×10^6
July 4, 60	A	2.3×10^4
July 22, 60	R	4.9×10^6
Aug. 1, 60	P	3.3×10^6
Aug. 1, 60	A	3.5×10^4
Aug. 22, 60	R	1.6×10^8

TABLE NO. 3 CONTINUED

Date 1960	Sample Point*	MPN per 100 ml, **	Date 1961	Sample Point*	MPN per 100 ml, **
Aug. 27, 60	R	5.4×10^6	Feb. 4, 61	R	2.3×10^6
Sept. 16, 60	R	7.9×10^6	Mar. 11, 61	R	7.0×10^6
Sept. 16, 60	A	5.4×10^6	Mar. 11, 61	A	9.5×10^4
Oct. 25, 60	R	1.7×10^7	Mar. 17, 61	R	1.1×10^6
Oct. 25, 60	P	4.9×10^6	May 20, 61	R	4.9×10^6
Oct. 25, 60	A	1.3×10^6	May 20, 61	A	7.9×10^4
Nov. 29, 60	R	3.3×10^6	May 25, 61	R	1.4×10^7
Nov. 29, 60	P	4.9×10^5	May 25, 61	A	4.9×10^5
Nov. 29, 60	A	7.9×10^4	June 10, 61	R	3.5×10^7
Dec. 20, 60	R	7.0×10^6	June 10, 61	A	2.3×10^5
			June 15, 61	R	2.2×10^6
			June 15, 61	A	1.3×10^5
Columbus Sewage Treatment Plant					
Sept. 5 59	R	2.3×10^7	Sept. 5, 59	A	3.3×10^6
Sept. 5, 59	P	1.3×10^7	Sept. 12, 59	A	7.9×10^4
Brookside Sewage Plant					
Sept. 11, 59	A	1.7×10^5			

*R = Raw sewage sample; P - Primary tank effluent; A = Aerator effluent; This system of designating samples is used throughout this report.

**MPN is reported in number of coliform organisms per 100 ml. sample on a presumptive basis.

TABLE NO. 4
EFFECT OF TREATMENT PROCESSES ON NUMBER OF COLIFORMS

Month	Average MPN: No./100 ml.			% Removal		
	Raw	Primary Effluent	Aeration Effluent	R - P	P - F	R - F
1959						
Aug.	6.0×10^7	------	2.0×10^6	--	--	96.7
Sept.	5.2×10^7	------	2.2×10^6	--	--	95.7
Oct.	4.9×10^6	7.9×10^6	3.6×10^6	0**	54.5	26.5
Nov.	1.8×10^6	3.3×10^6	1.1×10^6	0**	66.7	38.9
Dec.	7.9×10^6	4.9×10^6	2.6×10^5	38.0	94.7	96.7
1960*						
Feb.	4.6×10^6	2.5×10^6	1.5×10^6	45.7	40.0	67.4
Mar.	6.4×10^6	2.5×10^6	3.2×10^5	60.9	87.2	95.0
Apr.	1.4×10^7	2.3×10^6	7.1×10^4	83.5	96.9	99.5
May	1.5×10^7	1.1×10^7	1.7×10^5	26.7	98.5	98.9
June	4.9×10^6	3.5×10^6	4.9×10^3	28.6	99.9	99.9
July	4.9×10^6	3.3×10^6	2.3×10^4	32.7	99.3	99.5
Aug.	8.3×10^7	3.3×10^6	3.5×10^4	96.0	98.9	99.9
Sept.	7.9×10^6	------	5.4×10^6	--	--	31.6
Oct.	1.7×10^7	4.9×10^6	1.3×10^6	71.2	73.5	92.4
Nov.	3.3×10^6	4.9×10^5	7.9×10^4	85.2	83.9	97.6
Dec.	7.0×10^6	------	------	--	--	--
Aug.'58-Dec.'60 Average	1.8×10^7	4.2×10^6	1.2×10^6	47.4	82.8	82.4
1961						
Jan.	------	------	------	--	--	--
Feb.	2.3×10^6	------	------	--	--	--
Mar.	4.0×10^6	------	9.5×10^4	--	--	97.6
Apr.	------	------	------	--	--	--
May	1.4×10^7	------	4.9×10^5	--	--	96.5
June	1.9×10^7	------	1.8×10^5	--	--	99.1
Jan.'61-June'61 Average	9.8×10^6	------	2.6×10^5	--	--	97.7

R - P is removal in the primary tank
P - F is removal in the aeration tank
R - F is removal in the whole plant

* Plant not operated in January 1960 due to power cable failure
** During this month the primary effluent had a higher MPN than did the primary influent.

Settleable Solids

Table Five reports the settleable solids in the mixed liquor of the aeration tank.

TABLE NO. 5 SETTLEABLE SOLIDS IN MIXED LIQUOR

All settleable solids tests were run on the mixed liquor of the aeration tank, sampled when it was being agitated. All tabular values are in ml/l.

Date 1959 - 1960	Settleable Solids	Date 1960	Settleable Solids	Date 1960 - 1961	Settleable Solids
Aug. 15	5	Mar. 9	190	Nov. 18	640
Aug. 22	0	Mar. 16	160	Nov. 26	890
Aug. 29	3	Mar. 23	140	Dec. 4	698
Sept. 3	0	Apr. 1	170	Dec. 19	0
Sept. 5	3	Apr. 6	210	Dec. 21	0
Sept. 8	10	Apr. 11	230	Dec. 31	2
Sept. 12	5	Apr. 20	280	1961	
Sept. 15	5	Apr. 27	310	Jan. 3	630
Sept. 19	10	May 6	320	Jan. 28	413
Sept. 23	40	May 11	636	Feb. 4	726
Sept. 26	170	May 16	640	Feb. 8	833
Oct. 7	650	May 25	590	Feb. 15	929
Oct. 10	330	May 28	515	Feb. 25	927
Oct. 17	380	May 31	520	Feb. 27	925
Oct. 23	-	June 3	500	Mar. 11	830
Oct. 24	-	June 8	300	Mar. 15	915
Oct. 30	360	June 16	345	Mar. 25	900
Nov. 6	395	June 23	180	Apr. 7	870
Nov. 13	540	June 24	188	Apr. 12	920
Nov. 18	525	June 25	197	Apr. 14	750
Nov. 20	525	July 12	278	Apr. 17	900
Nov. 25	440	July 16	760	Apr. 20	820
Dec. 4	320	July 24	420	Apr. 21	870
Dec. 5	290	July 30	860	Apr. 24	780
Dec. 11	330	Aug. 4	854	Apr. 25	770
Dec. 13	400	Aug. 13	830	Apr. 26	680
Dec. 27	280	Aug. 20	830	May 5	620
1960		Sept. 13	633	May 9	100
Feb. 15	200	Oct. 3	280	June 7	122
Feb. 19	150	Oct. 9	610	June 13	160
Feb. 26	150	Oct. 13	736	June 15	170
Mar. 2	180	Nov. 14	997	June 16	260

Suspended and Volatile Solids

Tables six and seven report suspended solids by the Gooch crucible method and the loss on ignition of these samples. Table No. 6 reports the occasional individual sample analyzed for volatile and fixed solids during 1959. During 1960 volatile and fixed solids were generally run on each sample taken. Average monthly values are reported in Table No. 7 for the 1960-1961 period of operation. Statistical treatment of the volatile solids content of the plant components is given as part of Table No. 15.

TABLE NO. 6 SUSPENDED, VOLATILE and FIXED SOLIDS*

Date 1959	Sample Point	Susp. Solids	Fixed Solids	Volatile Susp. Solids
Sept. 8	R	198	20	178
Sept. 8	P	70	48	22
Sept. 15	R	180	0	180
Sept. 15	P	40	4	36
Sept. 15	A	47	6	41
Sept. 17	R	152	10	142
Sept. 17	P	69	8	61
Sept. 22	R	164	8	158
Sept. 22	P	56	17	39
Oct. 22	P	49	42	7
Oct. 22	R	456	376	80
Oct. 22	A	85	70	15
Nov. 3	R	180	36	144
Nov. 3	P	50	4	46
Nov. 3	A	35	9	26
Nov. 19	A	33	12	21
Dec. 19	R	64	6	58
Dec. 19	P	21	7	14
Dec. 19	A	10	3	7
Dec. 24	R	168	38	130
Dec. 24	P	40	9	31
Dec. 24	A	17	7	10

* All tabular values are ml/l

TABLE NO. 7 MONTHLY AVERAGE VALUES of SUSPENDED, VOLATILE and FIXED SOLIDS in PLANT SAMPLES

All tabular values in mg/l

Month 1960	Sample Point	Suspended Solids	Fixed Solids	Volatile Solids
February	R	136	--	--
"	P	30	--	--
"	A	13	--	--
March	R	166	36	130
"	P	37	6	31
"	A	9	1	8
April	R	159	32	127
"	P	34	9	25
"	A	6	1	5
May	R	170	41	129
"	P	34	4	30
"	A	6	3	3
June	R	174	31	143
"	P	43	8	35
"	A	9	2	7
July	R	204	52	152
"	P	79	25	54
"	A	13	5	8
August	R	217	61	156
"	P	112	36	76
"	A	10	5	5
September	R	230	42	188
"	P	63	--	--
"	A	6	--	--
October	R	228	47	181
"	P	41	15	26
"	A	11	3	8
November	R	192	53	139
"	P	30	14	16
"	A	11	5	6
December	R	266	--	--
"	P	44	--	--
"	A	45	--	--
Feb.,'60-Dec.,'60 Averages	R	195	44	149
	P	50	15	37
	A	13	3	6

Cont.

TABLE NO. 7 CONT.

Month 1961	Sample Point	Suspended Solids	Fixed Solids	Volatile Solids
January	R	168	--	--
"	A	33	--	--
February	R	154	54	100
"	A	14	3	11
March	R	118	13	105
"	A	4	4	0
April	R	74	12	62
"	A	14	1	13
May	R	148	50	98
"	A	24	8	16
June	R	139	17	122
"	A	13	0	13
Jan.,'61 June,'61 Averages	R	134	29	97
	A	17	3	11
		% Removal		
Feb.-Dec.'60				
R-P*		74	63	75
P-F*		74	80	84
R-F*		93	93	96
Jan.,'61 - June,'61				
R-F*		87	90	89

* R-P is removal in the primary tank.
* P-F is removal in the aeration tank and its settling compartment.
* R-F is removal in the whole plant.

TABLE NO. 8 DISSOLVED OXYGEN CONCENTRATION

Date	Sample Point	Dissolved Oxygen, mg/l
1959		
Sept. 2	R	1.90
Sept. 2	P	0
Sept. 2	A	3.32
Nov. 23	A	1.06
Dec. 16	R	3.08
Dec. 21	R	2.06
Dec. 21	A	1.48
1960		
Mar. 2	R	3.52
Mar. 2	A	9.30
May 5	A	4.04
May 18	A	1.66
June 1	A	4.36
June 14	A	2.80
July 9	A	0.64
July 14	A	3.74
Aug. 6	A	1.68
Aug. 9	A	0.44
Aug. 27	R	0.00
Aug. 27	A	0.44
Oct. 3	R	0.00
Nov. 26	A	0.70
1961		
Jan. 28	A	5.72
Feb. 10	A	4.44
Feb. 22	A	2.86
Mar. 23	A	7.10
Apr. 5	A	4.80
Apr. 22	A	6.40
June 7	A	5.08
June 15	A	4.58

TABLE NO. 9 HYDROGEN ION CONCENTRATION - pH

Date	Sample Point		
	R	F	A
1959			
Oct. 17	7.6	7.25	7.5
Oct. 24	7.6	7.2	7.6
Nov. 14	7.0	7.0	7.2
1960			
Feb. 27	7.7	7.5	7.2
Mar. 5	7.8	7.6	7.2
Mar. 10	7.7	7.6	--
Apr. 2	7.9	7.4	7.3
Apr. 7	7.6	7.3	7.5
Apr. 23	7.6	7.4	7.1
May 12	7.0	7.0	7.0
May 26	7.0	7.0	7.0
Sept. 19	7.0	6.9	7.2
Nov. 1	7.3	6.7	7.0
1961			
Mar. 23	7.4	--	7.3
Average	7.4	7.2	7.2

TABLE NO. 10 DEOXYGENATION RATE CONSTANT - k

Date	Oct. 28 1959	Nov. 27 1959	Dec. 21 1959	Mar. 9 1960	Mar. 9 1960	Mar. 30 1960	Apr. 4 1960	Apr. 18 1960	May 17 1960	Sept. 16 1960	Oct. 15 1960
Sample Point	A	A	A	A	A (1)	A	A	A	R	A	A
Days:	mg/l of BOD at end of time (days)										
1	4.8	1.3	0	4.6	4.6	1.9	0.4	0.7	16	0.3	0.7
2	8.3	3.6	---	3.4	6.8	7.5	0.8	1.8	---	1.7	2.7
3	11.2	9.0	4.2	4.0	8.6	13.8	1.8	2.6	31	3.7	3.3
4	11.4	10.8	5.4	5.6	10.4	19.8	---	4.0	60	4.3	4.0
5	10.9	11.7	9.6	5.8	14.4	32.9	4.6	5.4	60	5.7	6.3
6			14.4	7.4	23.0	56.	13.3	12.8	82	8.7	7.7
7			40.2	8.8	37.5	76.	25.7	25	84	11.0	10.0
8			61.7	11.1	50.	---	49.0	29	93	15.3	13.7
9			---	14.4	68.	---	52.0	39	128	21.3	---
10			84.	29.0		127	56	32	140	33.3	52
11						---	89	---			56
12						128	---	---			
13						---	---	---			
14						126	97	100			
15						---	---				
16						---	---				
17						---	---				
18						---	117				
19						133	---				
20						---	---				
21						---	122				
22						---	---				
23						135	---				
24						---	---				
25						---	---				
26						137	---				
27							---				
28							126				
k	0.581										

(1) This data for Columbus Sewage Plant Effluent

TABLE NO. 11 SLUDGE VOLUME INDEX (SVI) AND SUSPENDED SOLIDS OF MIXED LIQUOR

Date	S.V.I. ml/g	Suspended Solids mg/l	Date	S.V.I. ml/g	Suspended Solids mg/l
1959			1960		
Nov. 18	597	880	July 30	422	2037
Dec. 5	181	1600	Aug. 4	339	2522
1960			Aug. 13	236	3403
Feb. 19	115	1310	Aug. 20	209	3965
Mar. 3	105	1712	Sept. 13	437	1447
Mar. 9	100	1883	Oct. 3	142	1978
Mar. 16	83	1920	Oct. 9	485	1258
Apr. 1	67	2522	Oct. 13	460	1600
Apr. 6	74	2854	Nov. 18	1040	617
Apr. 11	80	2880	Nov. 26	928	957
Apr. 20	85	3304	Dec. 4	845	825
Apr. 27	92	3356	1961		
May 6	88	3625	Jan. 3	891	770
May 11	184	3445	Jan. 28	221	1872
May 16	234	2735	Feb. 4	232	3135
May 25	431	1200	Feb. 8	238	3605
May 28	364	1378	Feb. 15	208	4365
May 31	396	1312	Feb. 25	171	5432
June 3	309	1620	Feb. 27	178	5206
June 8	172	1378	Mar. 11	148	5580
June 16	177	1955	Mar. 15	154	5937
June 25	76	2160	Apr. 14	214	3510
July 12	357	778	Apr. 21	175	4984
July 18	685	1103	May 5	112	5529
July 24	488	861	June 7	39	3160
			June 15	37	4650

TABLE NO. 12 NITROGEN CONTENT OF PLANT EFFLUENT

Date 1960	Sample Point	Nitrogen as NO_3, mg/l
May 19	A	0.02

TABLE NO. 13
VOLUMETRIC SEWAGE FLOW RATE THROUGH PLANT

Month	Flow g/d*	Theoretical Detention, Hours		
		Primary Tank	Aeration	Secondary Settling
1959				
Aug.	850	27.1	15.5	5.2
Sept.	850	27.1	15.5	5.2
Oct.	878	26.2	15.0	5.1
Nov.	956	24.1	13.8	4.6
Dec.	988	23.3	13.3	4.5
1960				
Feb.	922	25.0	14.3	4.8
Mar.	875	26.4	15.1	5.1
Apr.	917	25.1	14.4	4.8
May	903	25.5	14.6	4.9
June	915	25.2	14.4	4.9
July	936	24.6	14.1	4.7
Aug.	822	28.0	16.0	5.4
Sept.	928	24.9	14.2	4.8
Oct.	778	29.4	16.8	5.7
Nov.	868	26.5	15.2	5.1
Dec.	939	24.6	14.0	4.7
Σ	14325	413.0	236.3	79.5
Aug.'59-Dec.'60 Average	895	25.8	14.8	5.0
1961				
Jan.	832	----	14.2	4.8
Feb.	851	----	20.3	6.8
Mar.	648	----	20.4	6.9
Apr.	717	----	18.4	6.2
May	762	----	17.3	5.8
June	875	----	15.1	5.1
Σ	4585	----	105.7	35.6
Jan.'61-June'61 Average	764	----	17.6	5.9

* g/d, gallons per 24-hour day

TABLE NO. 14
PLANT OPERATIONAL CHARACTERISTICS

Date	Raw BOD mg/l	% Removal in plant	lb. BOD/day to plant	lb. BOD removed per day	KWH per day	KWH/lb. BOD Removed	Cu. ft. free air per hr.	Cu.ft. air/ lb. of BOD to Plant	Cu.ft. air/ lb. BOD Removed	Cu.ft. air/ gal. sewage
1959										
Aug.	156	84	1.106	0.928	2.88	3.12	51.1	1107	1320	1.44
Sept.	154	82	1.092	0.895	2.80	3.13	50.5	1110	1354	1.43
Oct.	127	88	0.900	0.819	2.56	3.12	53.2	1373	1560	1.45
Nov.	122	85	0.873	0.827	9.17	11.09	71.4	1760	2070	1.79
Dec.	118	84	0.870	0.812	7.72	9.50	78.0	1980	2310	1.89
1960										
Feb.	126	83	0.969	0.804	8.80	10.95	68.8	1724	2078	2.25
Mar.	173	93	1.262	1.211	7.94	6.56	79.2	1505	1569	2.17
Apr.	154	94	1.174	1.107	7.13	6.50	85.0	1732	1843	2.23
May	142	88	1.069	0.941	7.05	7.49	80.1	2022	2298	2.39
June	153	95	1.211	1.150	5.86	5.10	37.7	1342	1413	1.71
July	175	95	1.372	1.304	5.80	4.45	30.0	1050	1104	1.53
Aug.	198	97	1.357	1.316	5.53	4.20	30.0	1032	1098	1.75
Sept.	224	83	1.733	1.606	5.28	3.18	60.0	830	865	1.55
Oct.	202	96	1.311	1.259	5.51	4.38	60.0	1098	1144	1.85
Nov.	213	95	1.542	1.465	5.68	3.88	60.0	934	983	1.66
Dec.	224	80	1.754	1.403	5.61	4.00	58.0	794	992	1.48
Aug.'59-Dec.'60 Average	163	90	1.239	1.119	5.96	5.67	65.8	1336	1500	1.79
1961										
Jan.	230	87	1.788	1.556	7.59	4.88	94.5	1268	1458	2.43
Feb.	188	95	1.021	0.970	11.05	11.34	206.4	4852	5107	7.61
Mar.	85	89	0.513	0.457	10.79	23.61	196.8	9207	10335	7.29
Apr.	132	92	0.789	0.726	10.41	14.34	192.0	5840	3347	6.43
May	156	89	0.930	0.881	10.17	11.53	186.3	4523	5083	5.88
June	191	95	1.394	1.324	10.25	7.74	182.0	3254	3426	5.18
Jan.'61-June'61 Average	135	91	1.082	0.983	10.04	12.24	177.3	4824	5293	5.80

Table No. 15 supplies statistical information relative to the operation of this plant as measured by change in BOD, suspended and volatile solids through the plant units.

TABLE NO. 15 STATISTICAL SUMMARY OF OPERATING CHARACTERISTICS AS MEASURED BY BOD, SUSPENDED AND VOLATILE SOLIDS. Parameters for 22 months of operation

Test (5)	Sample Point	Number of Replicates, n	Arithmetic Mean M, mg/l	Standard Deviation, σ, mg/l	Coefficient of variation, Cv, % (1)	95% Confidence limit, mg/l (2)	Range R mg/l (3)
1	2	3	4	5	6	7	8
Aug. '59-Dec. '60							
BOD	R	341	166	51	31	5	253
BOD	P	337	86	24	28	3	114
BOD	A	320	15	12	84	1	58
SS	R	162	181	58	32	9	247
SS	P	154	39	13	34	2	66
SS	A	160	15	13	85	2	59
VS (4)	R	70	147	41	28	10	198
VS (4)	P	68	29	12	42	3	49
VS (4)	A	59	8	6	37	1	26
Jan. '61-June '61							
BOD	R	100	153	63	40	12	250
BOD	A	95	15	12	78	2	54
SS	R	41	142	49	35	15	194
SS	A	43	19	16	84	5	53
VS	R	27	96	38	40	14	128
VS	A	20	14	7	45	3	28

Notes:
(1) $Cv = \sigma/M$ expressed as %
(2) 95 % confidence limit in $M = \pm 1.96\ \sigma/\sqrt{n}$
(3) Range R is the difference between the largest and the smallest value of n observations.
(4) Volatile solids were not run during August 1959, thus this is a 15-month period of record.
(5) BOD's reported are 5-day, 20^0C BOD results. Suspended solids are run by the Gooch crucible method. Both tests conform to Standard Methods.

Table No. 16 presents data on sludge depth accumulation in the USPH Service anaerobic solids contact tank after various periods of continuous operation. Sludge depths are measured on longitudinal centerline of the tank. Sludge accumulation started Aug. 2, 1959.

TABLE NO. 16 ACCUMULATED SLUDGE DEPTHS

Date	Distance from inlet end, inches	Total Depth of Sludge, inches:
Oct. 10, 1959	11	12
Oct. 10, 1959	38	2 to 3
Oct. 10, 1959	80	1.5
Feb. 28, 1960	17	12
Feb. 28, 1960	35	10
Feb. 28, 1960	54	6
Feb. 28, 1960	78	4
Apr. 2, 1960	18	16
Apr. 2, 1960	24	16
Apr. 2, 1960	35	4
Apr. 2, 1960	53	3
Aug. 6, 1960	15	14.5
Aug. 6, 1960	24	14.5
Aug. 6, 1960	34	16.5
Aug. 6, 1960	46	15
Aug. 6, 1960	56	15.5
Nov. 11, 1960	16	15
Nov. 11, 1960	72	16
Jan. 23, 1961	19	15.6
Jan. 23, 1961	72	16.5
June 15, 1961	24	14.8
June 15, 1961	44	14.8
June 15, 1961	80	13.2

Table No. 17 presents Chemical Oxygen Demand (COD) compared with BOD tests on the same samples.

TABLE NO. 17 CHEMICAL OXYGEN DEMAND (COD) *

Date	Sample Point	COD mg/l	BOD mg/l	Date	Sample Point	COD mg/l	BOD mg/l
1960				1960			
May 19	A	88	26	Nov. 22	P	186	98
May 21	A	33	3	Nov. 22	A	71	12
May 28	A	34	10	Dec. 1	R	512	220
June 4	P	116	74	Dec. 1	P	212	103
June 22	R	277	127	Dec. 1	A	280	68
June 22	A	49	6	Dec. 20	R	562	245
July 6	R	365	167	Dec. 20	P	229	114
July 6	A	31	4	Dec. 20	A	234	59
July 8	P	171	104	May.'60	R	442	
July 15	R	351	140	Dec.'60	P	187	
July 15	A	31	8	Averages	A	94	
July 29	P	213	90	1961			
Aug. 5	R	341	210	Jan. 21	R	408	209
Aug. 5	A	22	6	Jan. 21	A	97	23
Aug. 26	R	295	94	Jan. 28	R	529	286
Aug. 26	A	43	2	Jan. 28	A	130	26
Sept. 2	P	161	68	Feb. 4	R	620	273
Sept. 9	R	550	216	Feb. 4	A	137	20
Sept. 9	P	228	98	Feb. 11	R	631	239
Sept. 16	A	59	6	Feb. 11	A	127	14
Sept. 23	R	417	222	Feb. 25	A	58	6
Sept. 23	A	74	28	Mar. 4	R	258	165
Oct. 1	P	201	101	Mar. 4	A	85	14
Oct. 8	R	453	190	Mar. 18	R	282	132
Oct. 8	P	195	99	Mar. 18	A	66	14
Oct. 8	A	60	9	Apr. 29	R	255	123
Oct. 15	R	677	223	Apr. 29	A	66	18
Oct. 15	P	179	84	May 6	R	294	117
Oct. 15	A	32	6	May 6	A	72	15
Oct. 18	R	410	180	May 27	R	246	232
Oct. 18	P	188	89	May 27	A	94	49
Oct. 18	A	61	8	June 13	R	338	161
Oct. 27	R	478	218	June 13	A	38	4
Oct. 27	P	171	92	Jan.'61-	R	386	
Oct. 27	A	358	134	June'61	A	88	
Nov. 22	R	497	223	Averages			

* Corrections for chloride content not made.

In Table No. 18 is compiled data relating to BOD and Suspended Solids loading of and removal by the primary and secondary treatment units of the plant. Results are expressed in lbs. of BOD or Suspended Solids loaded into or removed by a tank per day per 1000 gallons capacity. The primary tank has a capacity of 960 gallons and the secondary tank, composed of aeration plus settling, has a combined capacity of 735 gallons. The data of this table are the basis of the curves of Figure No. 18. All tabular values are monthly average lbs. of BOD or SS per day per 1000 gal. tank capacity.

TABLE NO. 18 BOD and SUSPENDED SOLIDS LOADING and REMOVAL

Date	Primary Unit				Secondary Unit			
	Suspended Solids		BOD		Suspended Solids		BOD	
	Loading	Removal	Loading	Removal	Loading	Removal	Loading	Removal
1959								
Aug.	1.817	1.599	1.152	0.438	0.289	0*	0.935	0.853
Sept.	1.381	1.036	1.138	0.330	0.434	0.183	1.041	0.791
Oct.	1.541	1.202	0.969	0.213	0.448	0.169	0.986	0.836
Nov.	1.163	0.802	1.014	0.162	0.466	0.239	1.106	0.911
Dec.	1.176	0.870	1.010	0.394	0.392	0.303	0.807	0.605
1960								
Feb.	1.090	0.850	1.009	0.636	0.314	0.178	0.481	0.251
Mar.	1.262	0.980	1.315	0.842	0.367	0.278	0.615	0.546
Apr.	1.267	1.001	1.223	0.697	0.354	0.292	0.689	0.595
May	1.334	1.067	1.114	0.524	0.348	0.287	0.768	0.594
June	1.384	1.038	1.261	0.542	0.446	0.353	0.903	0.820
July	1.659	1.012	1.421	0.529	0.839	0.701	1.168	1.082
Aug.	1.550	0.744	1.414	0.721	1.044	0.950	0.914	0.859
Sept.	1.875	1.369	1.805	1.083	0.663	0.600	0.947	0.843
Oct.	1.541	1.264	1.366	0.751	0.332	0.265	0.803	0.732
Nov.	1.448	1.216	1.606	0.915	0.295	0.187	0.799	0.705
Dec.	2.171	1.802	1.827	0.950	0.469	0*	1.014	0.591
Aug. '59-Dec. '60 Average	1.479	1.116	1.290	0.608	0.471	0.312	0.874	0.726
$\frac{\text{Removal}}{\text{Loading}} \times 100$		75.5		47.1		66.2		83.1

Continued

TABLE NO. 18 CONTINUED

Date	Primary Unit				Secondary Unit			
	Suspended Solids		BOD		Suspended Solids		BOD	
	Loading	Removal	Loading	Removal	Loading	Removal	Loading	Removal
1961								
Jan.					1.776	1.421	2.431	2.106
Feb.					1.137	1.035	1.388	1.319
Mar.					0.867	0.841	0.698	0.621
Apr.					0.602	0.488	1.073	0.987
May					1.279	1.074	1.348	1.200
June					1.379	1.255	1.895	1.800
Jan.'61-June'61 Average					1.173	1.019	1.472	1.339
$\frac{\text{Removal}}{\text{Loading}} \times 100$						86.9		91.0

* During these months the effluent had more suspended solids than did the secondary influent.

TABLE NO, 19 COMPRESSED AIR FACTORS

Dates of Operation	Compressor Type	Electrical Energy Used KWH/1000 cu. ft. air	Approx. Air Delivery cu. ft./ hr.
Aug. -Oct. 1959	Gast Model No. 0211-P3A-G8X 1/6 HP Motor	2.22	51.6
Nov. -Dec. 1959	Speedaire 1/2 HP Motor	4.70	74.7
Feb. -May 1960	Gast (Used) Model No. 0440 1/4 HP Motor	3.98	81.1
June-Dec. 1960	Gast (Used) Model No. 0440 1/3 HP Motor and reworked vanes	3.84	60.8
Feb. -June 1961	Binks Model CP 1/3A 1/3 HP Motor	2.26	194.2

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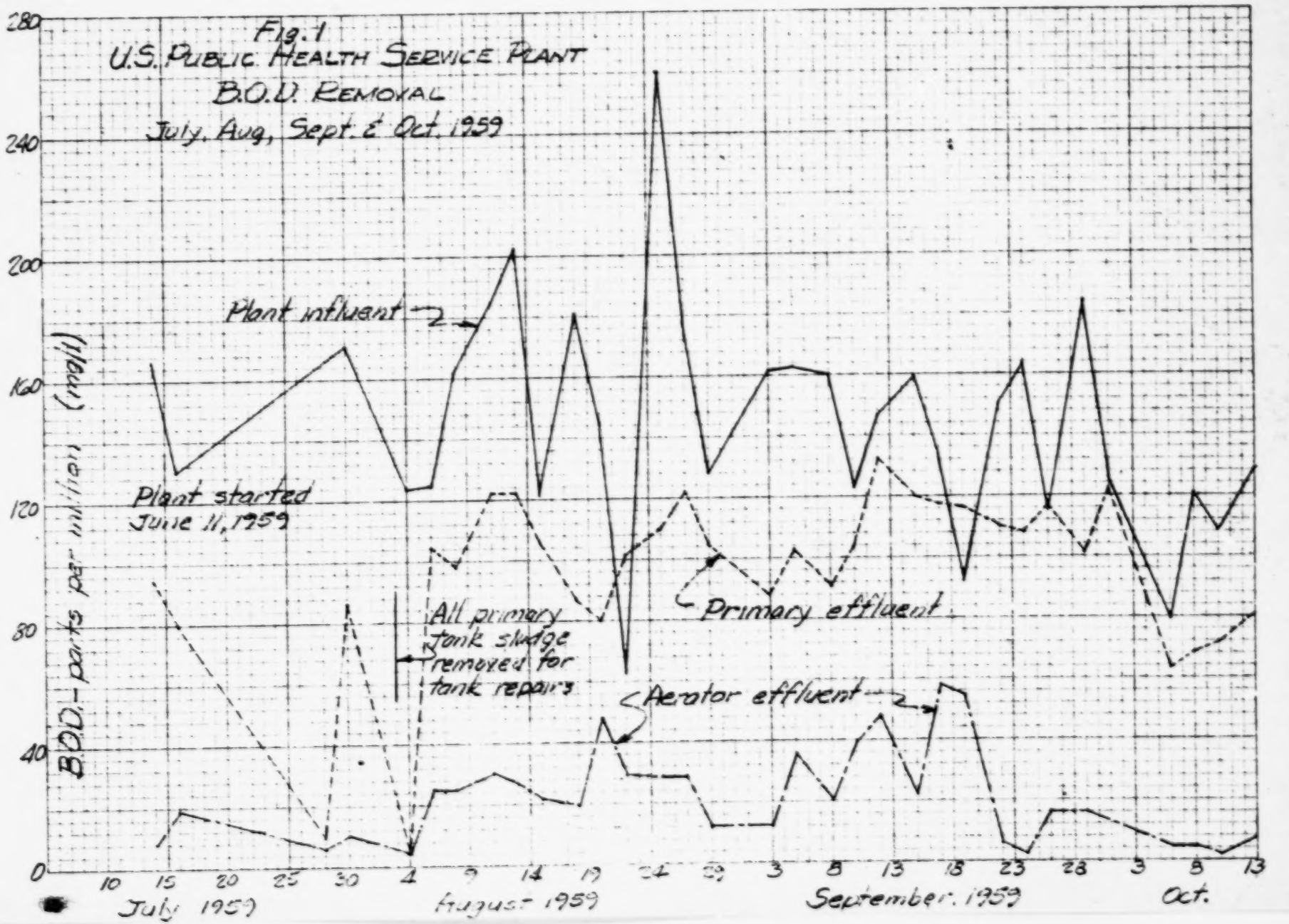

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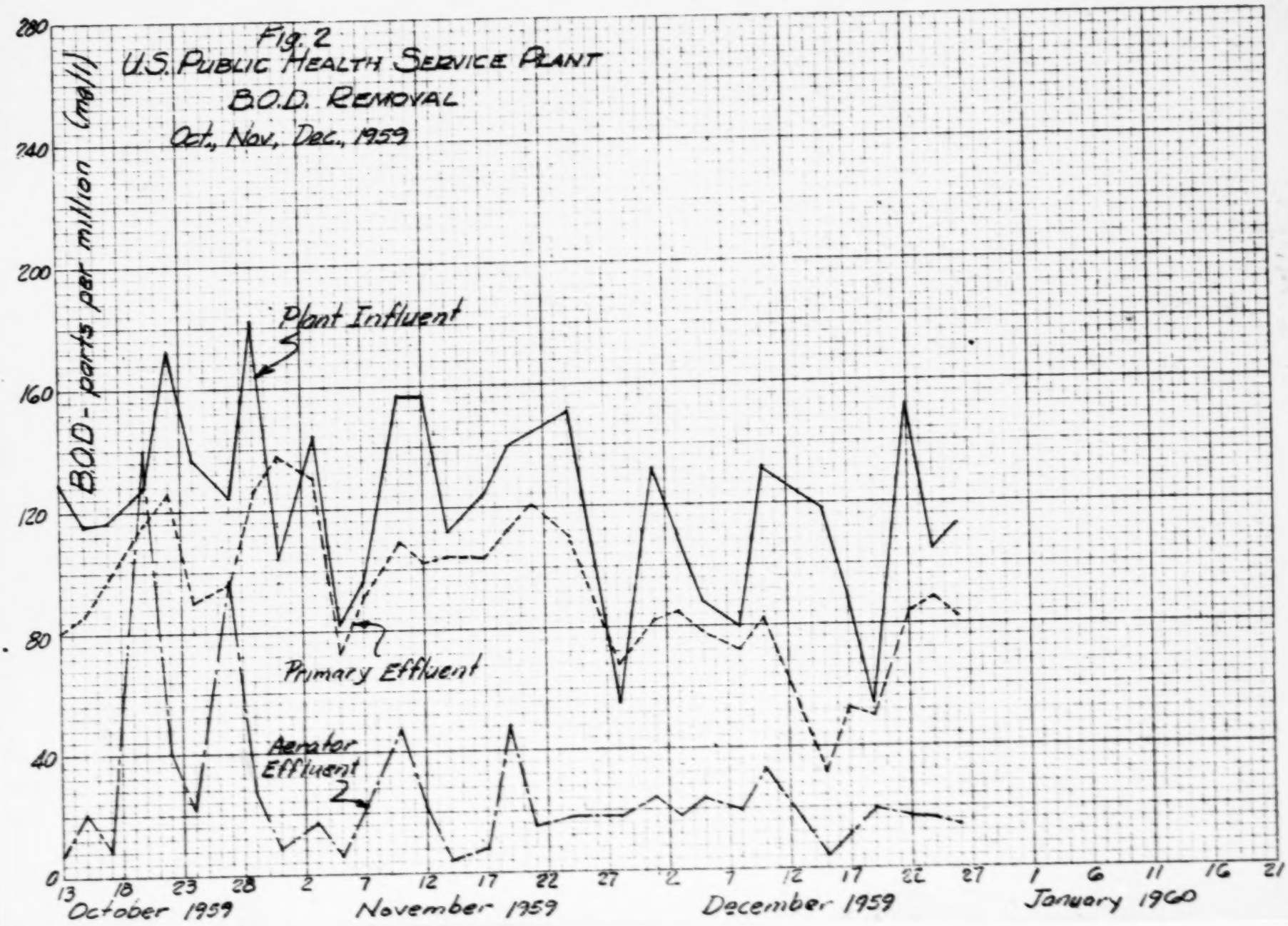

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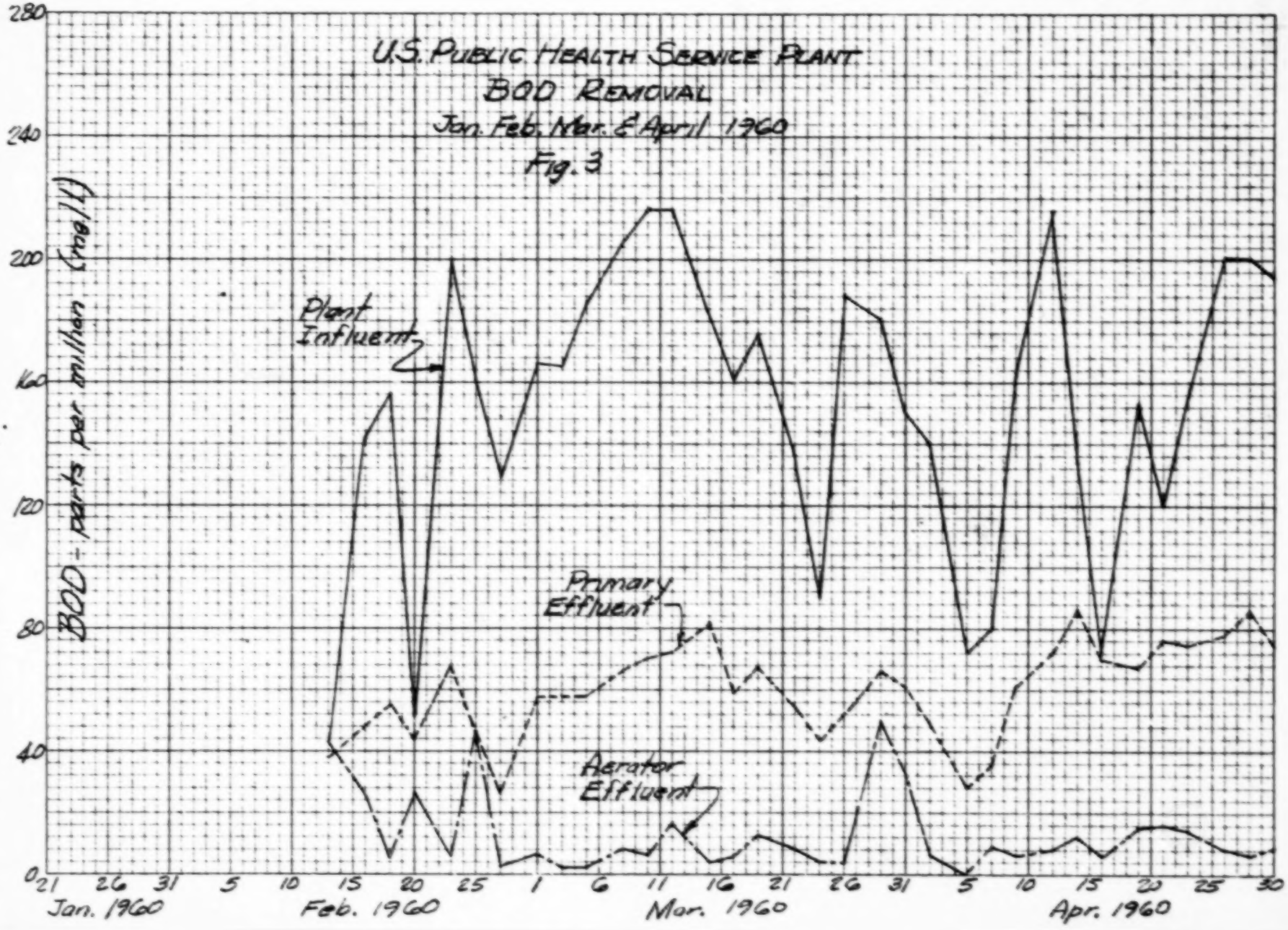

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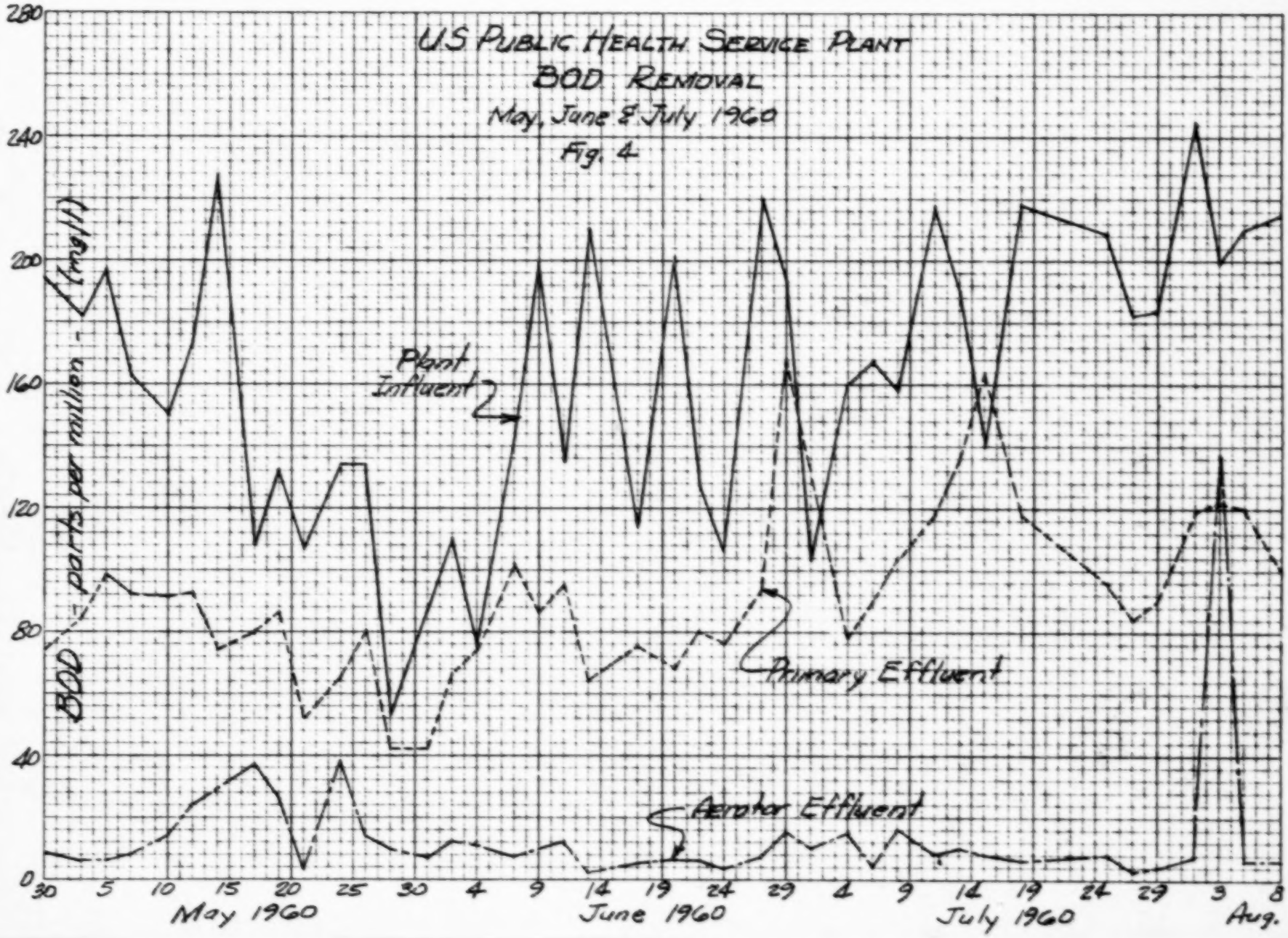

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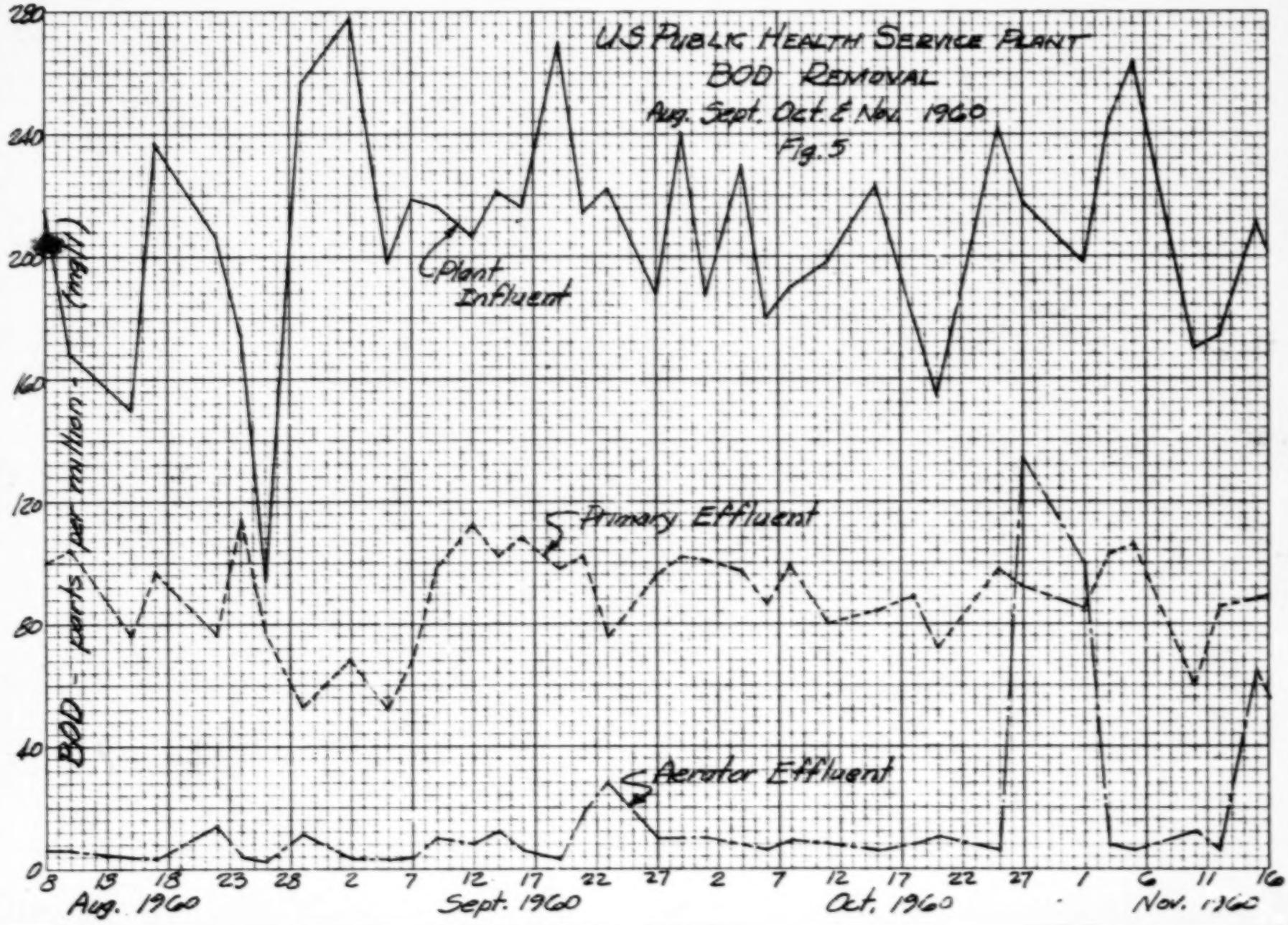

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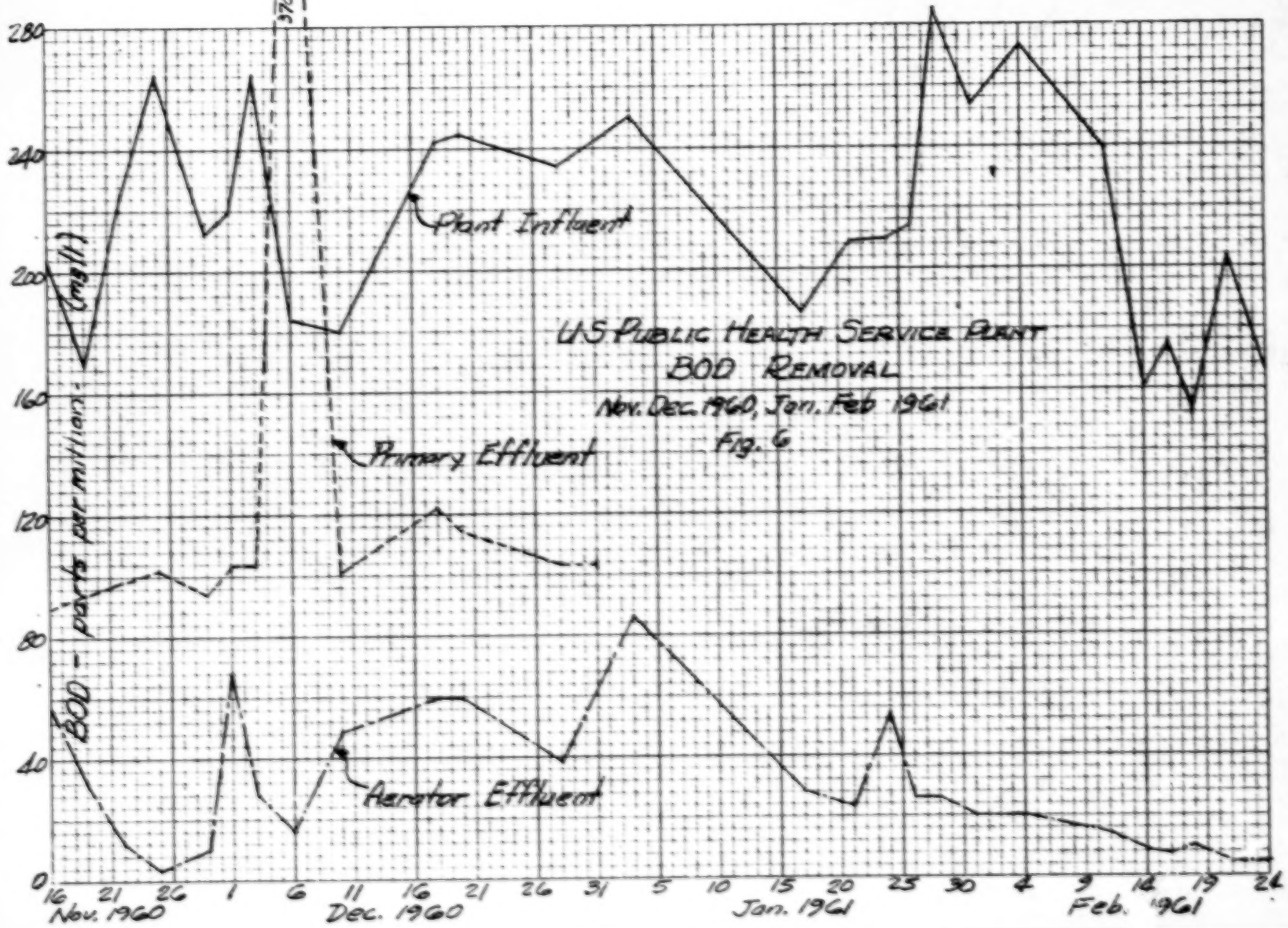

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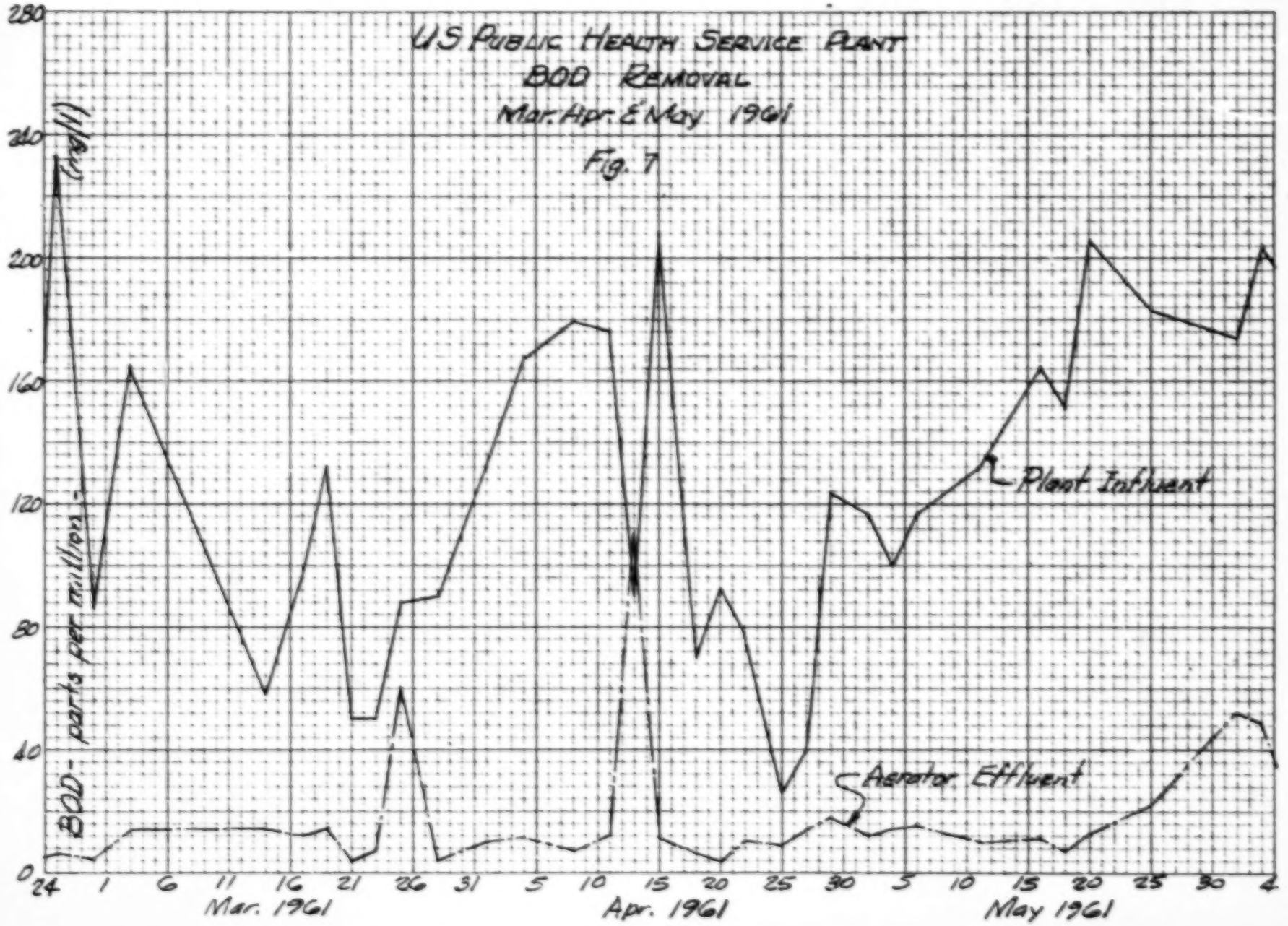

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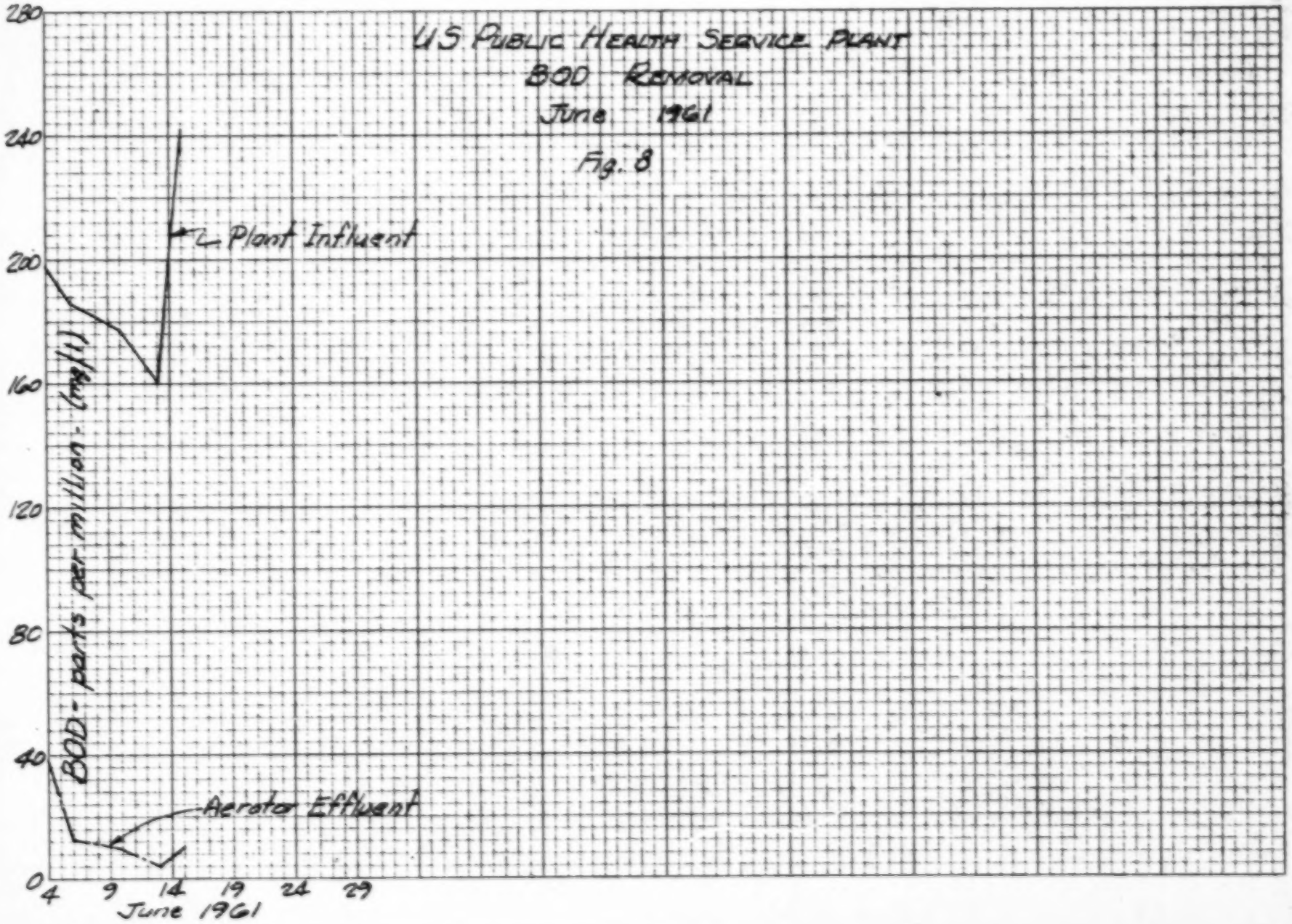
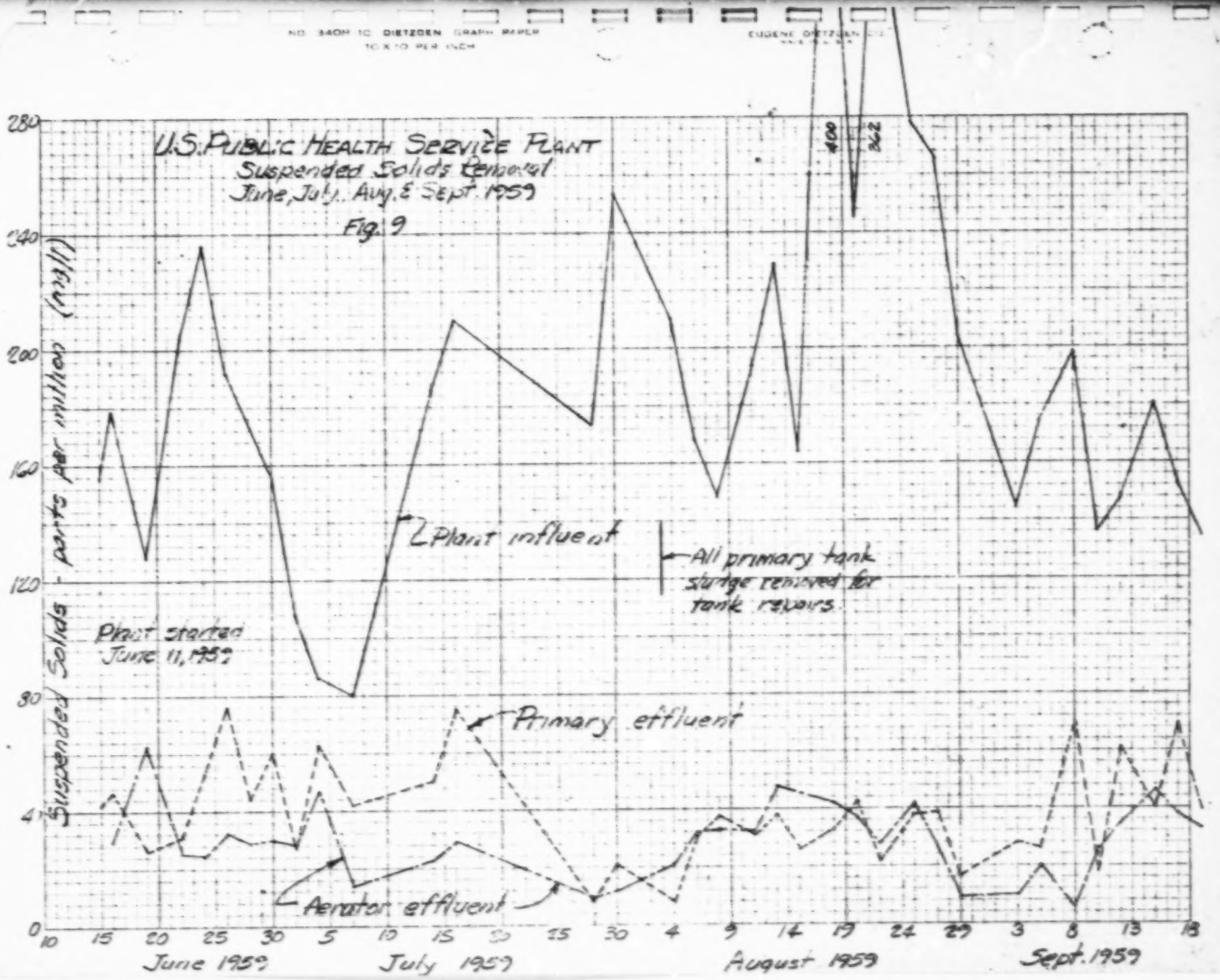
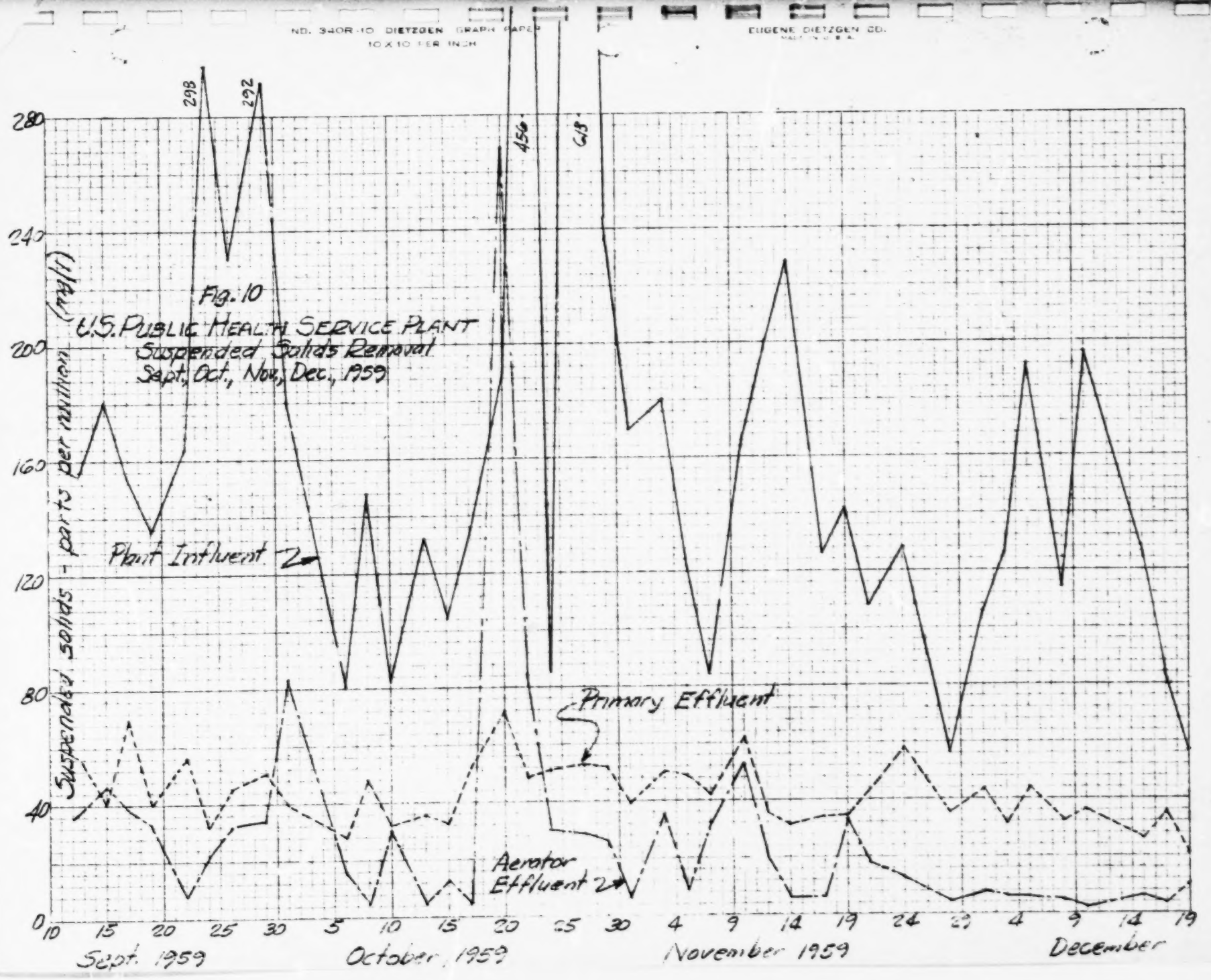
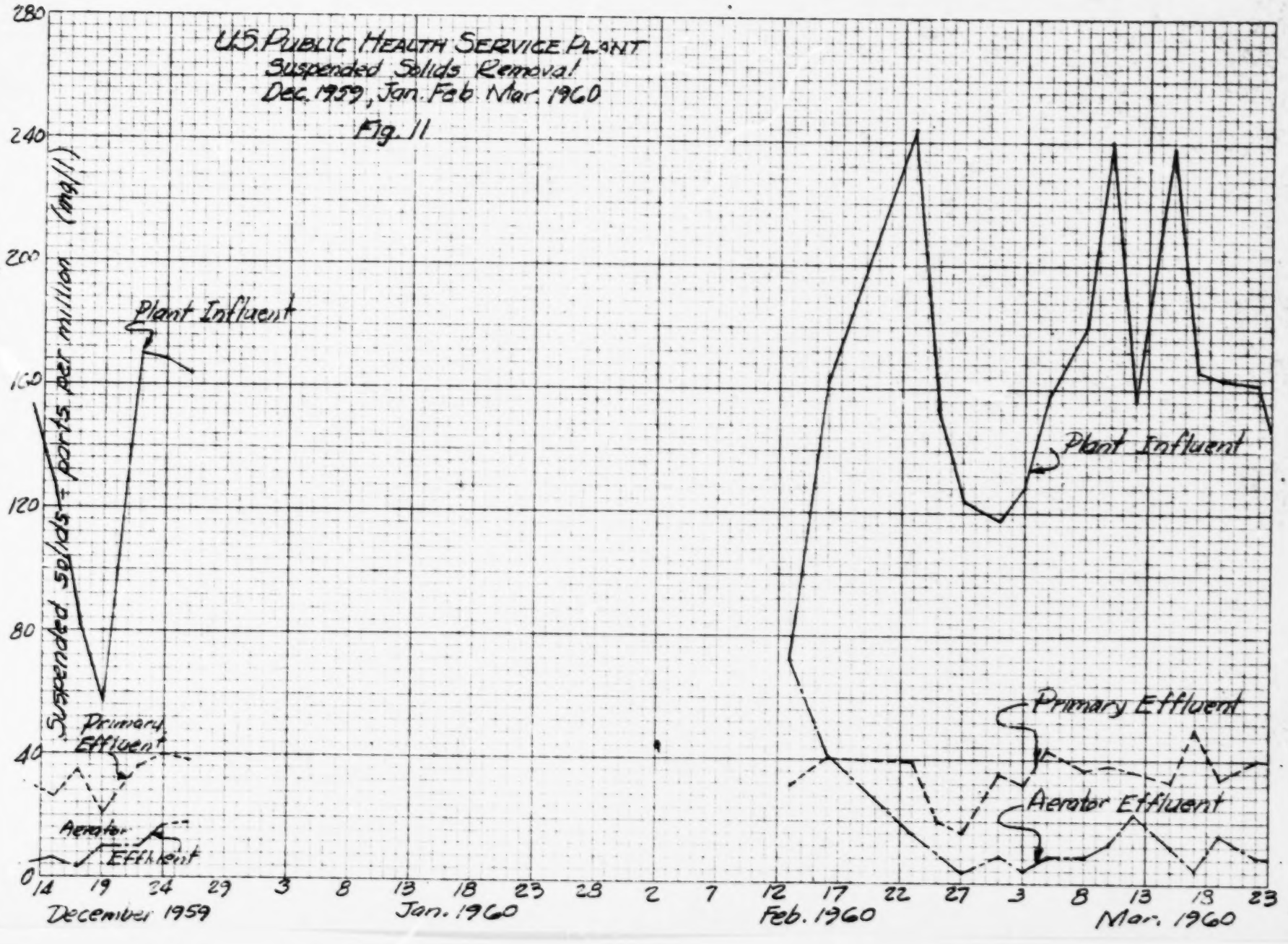



U.S. Public Health Service Plant
Suspended Solids Removal
June, July, Aug. & Sept. 1959
Fig. 9
Suspended Solids - parts per million (mg/l)
280
240
200
160
120
80
40
0
100
262
Plant influent
All primary tank sludge removed for tank repairs
Plant started June 11, 1959
Primary effluent
Aerator effluent
10 15 20 25 30 5 10 15 20 25 30 4 9 14 19 24 29 3 8 13 18
June 1959
July 1959
August 1959
Sept. 1959


ND. 340R-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH
EUGENE DIETZGEN CO.
298
292
456
618
280
240
200
160
120
80
40
0
Suspended solids - parts per million (mg/l)
Fig. 10
U.S. PUBLIC HEALTH SERVICE PLANT
Suspended Solids Removal
Sept, Oct., Nov, Dec., 1959
Plant Influent
Primary Effluent
Aerator Effluent
10 15 20 25 30 5 10 15 20 25 30 4 9 14 19 24 29 4 9 14 19
Sept. 1959
October, 1959
November 1959
December

NO. 340R-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH
KEUFFEL & ESSER CO.
MADE IN U.S.A.



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EUGENE DIETZGEN CO.
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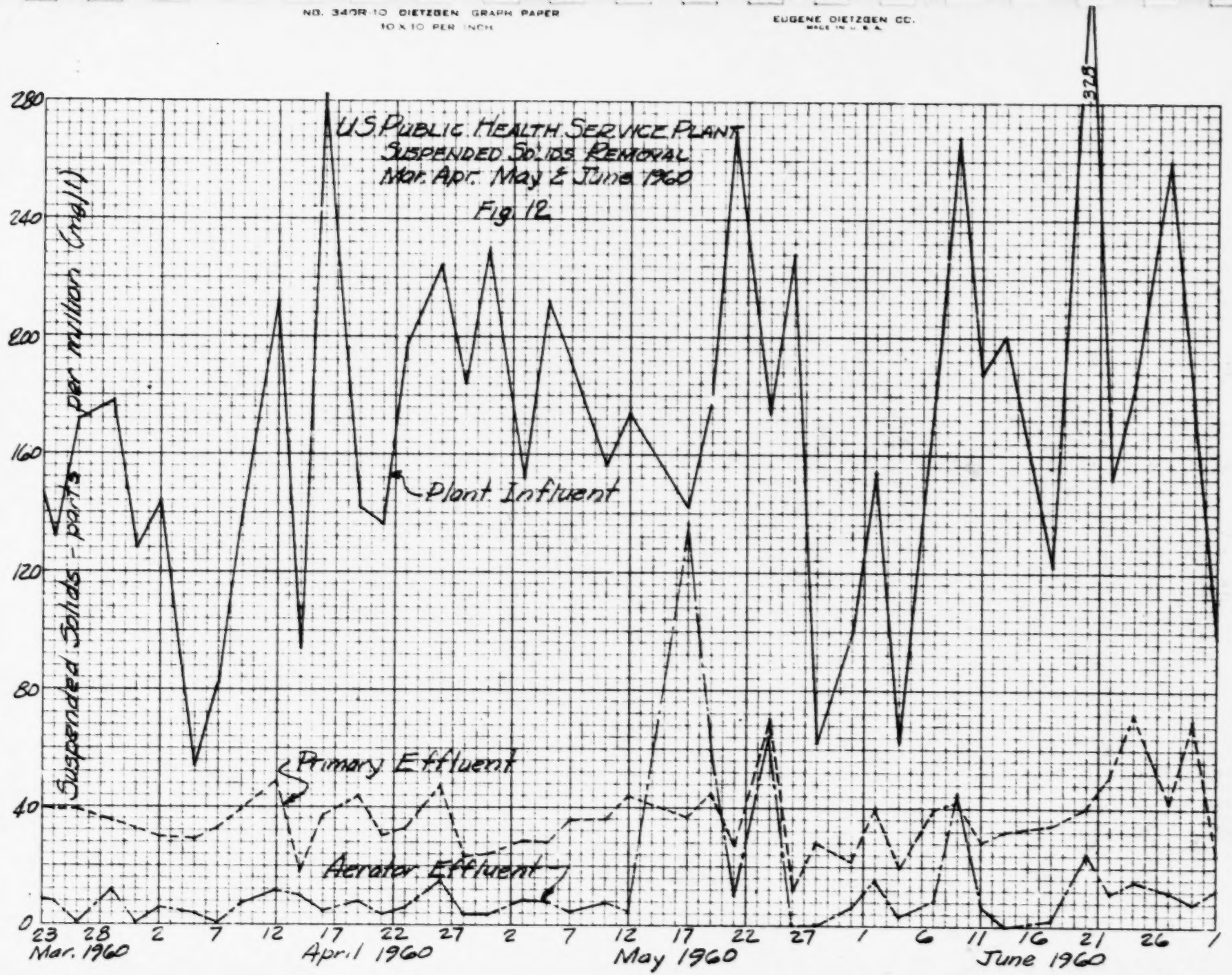

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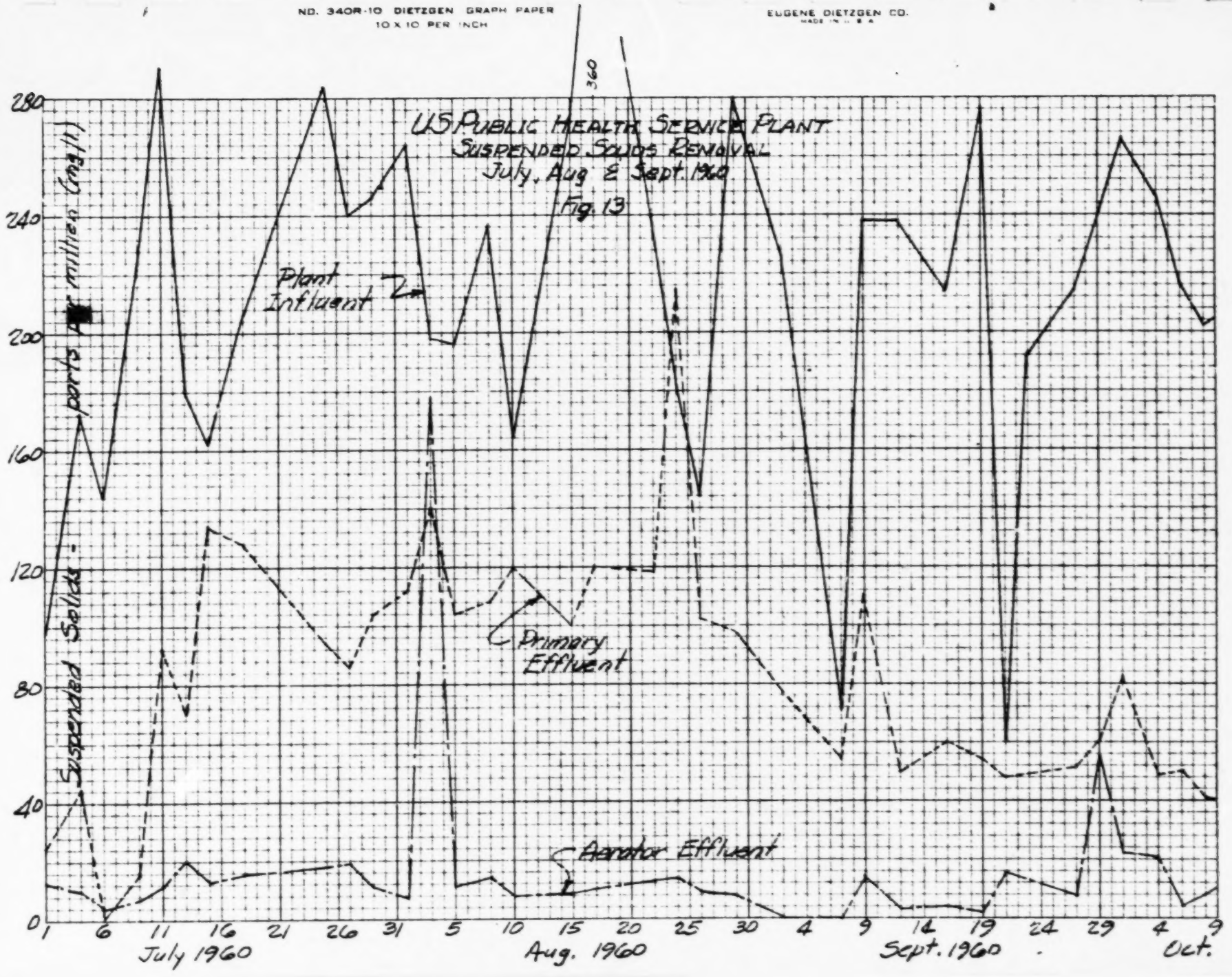

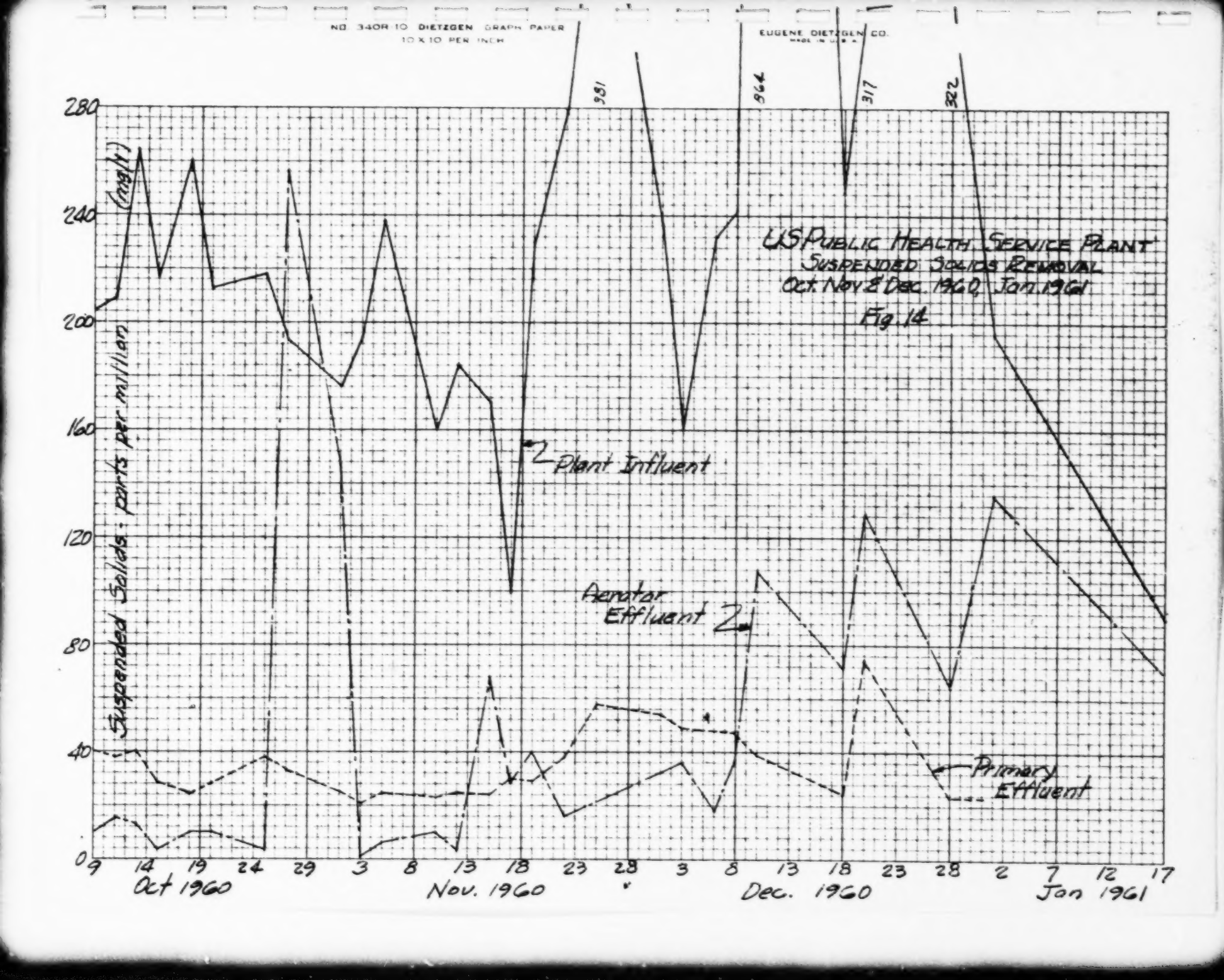
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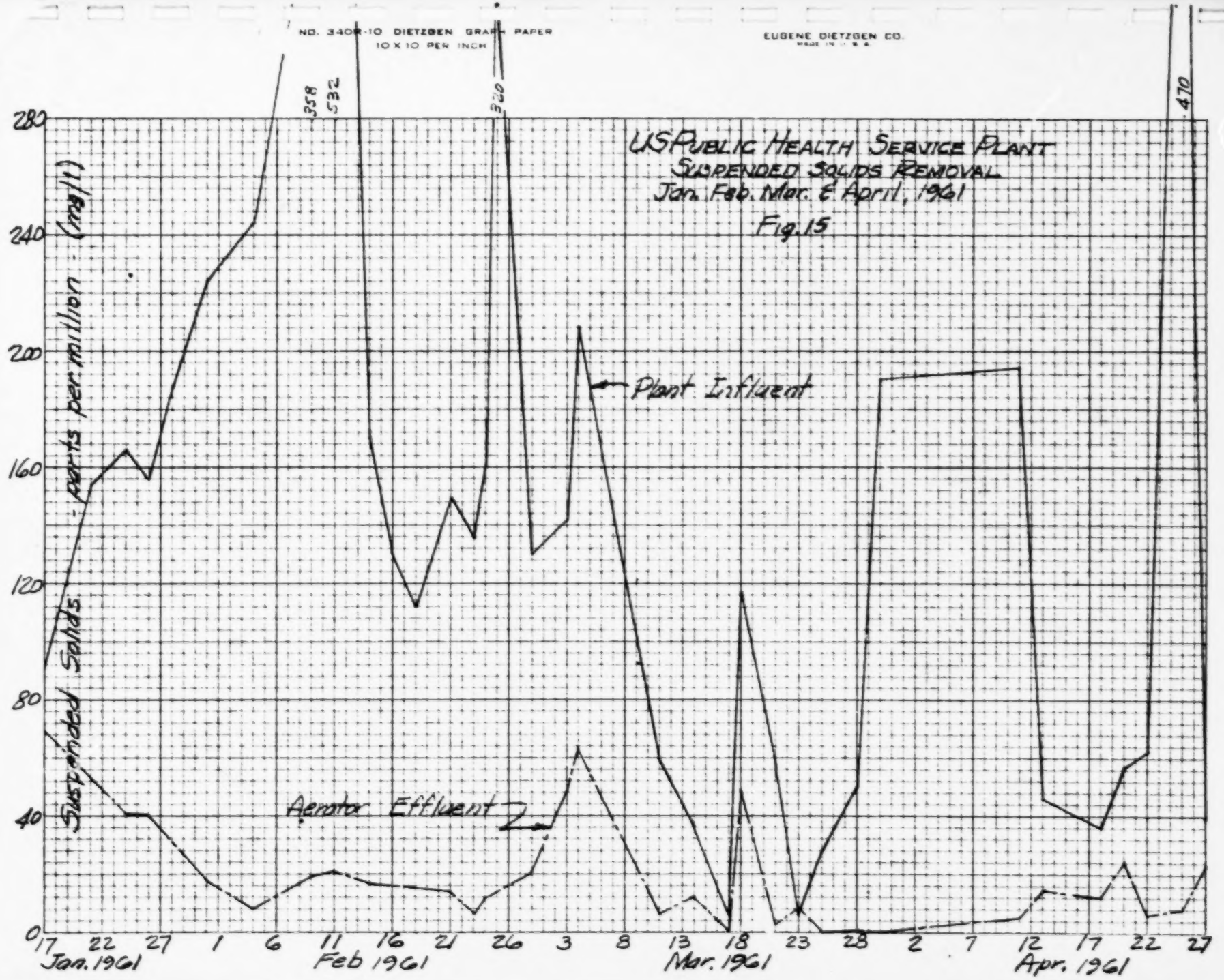
10 X 10 PER INCH
EUGENE DIETZGEN CO.
MADE IN U.S.A.
US PUBLIC HEALTH SERVICE PLANT
SUSPENDED SOLIDS REMOVAL
Oct. Nov & Dec. 1960, Jan. 1961
Fig. 14
Suspended Solids: parts per million (mg/l)
280
240
200
160
120
80
40
0
351
964
317
322
Plant Influent
Aerator Effluent
Primary Effluent
9 14 19 24 29 3 8 13 18 23 28 3 8 13 18 23 28 2 7 12 17
Oct 1960
Nov. 1960
Dec. 1960
Jan 1961



US PUBLIC HEALTH SERVICE PLANT
SUSPENDED SOLIDS REMOVAL
Jan. Feb. Mar. & April, 1961

Fig. 15

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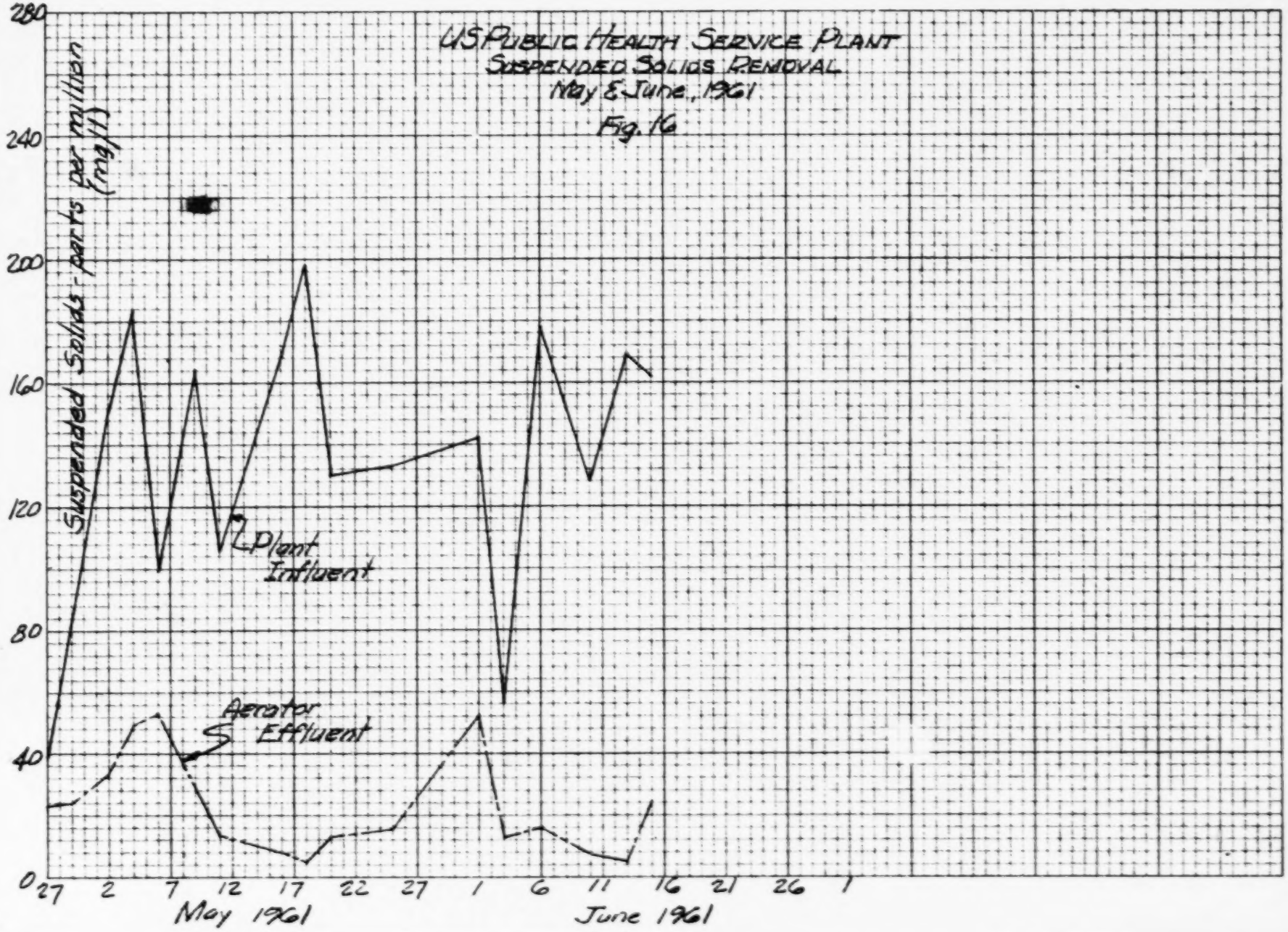
10 X 10 PER INCH
EUGENE DIETZGEN CO.
MADE IN U. S. A.



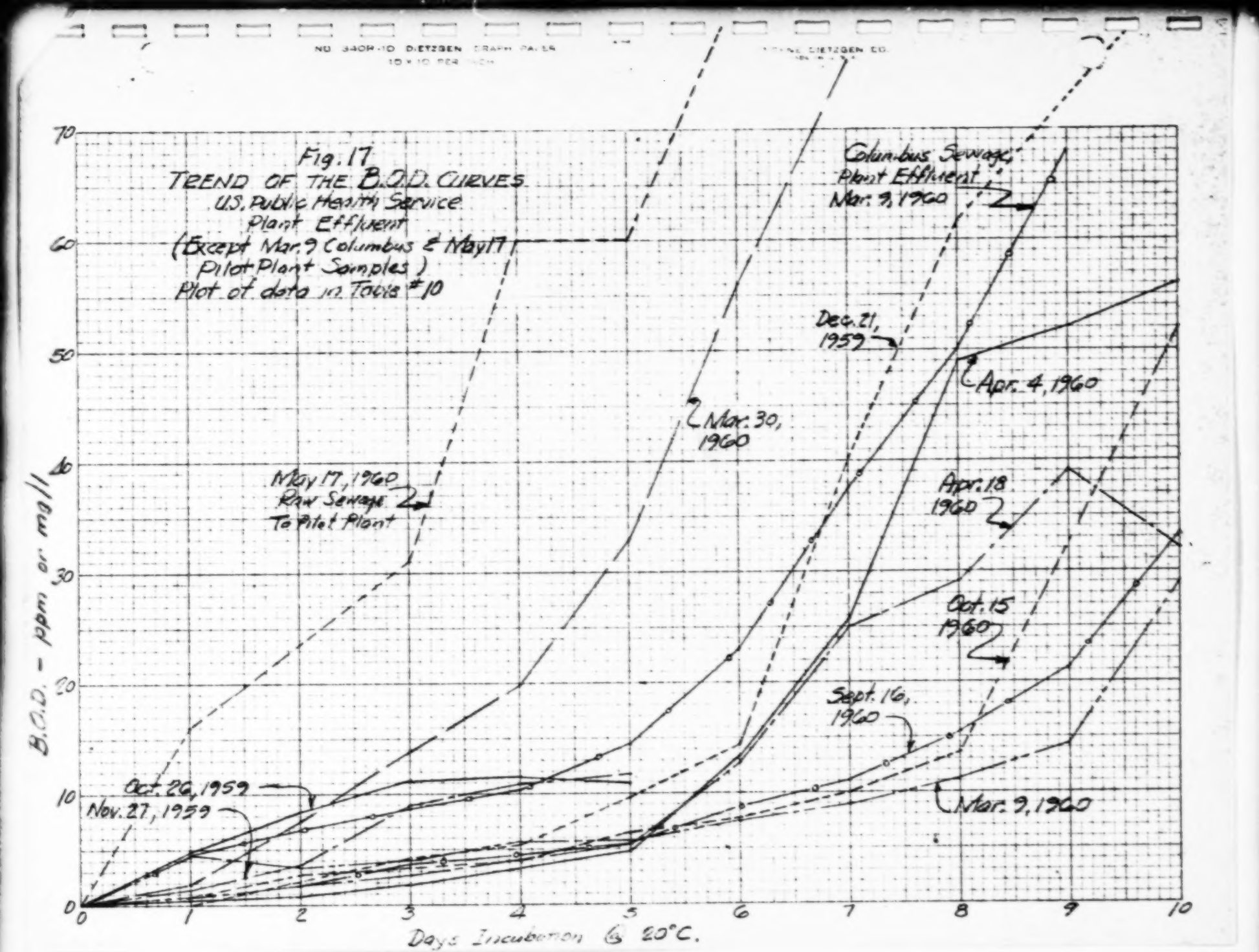
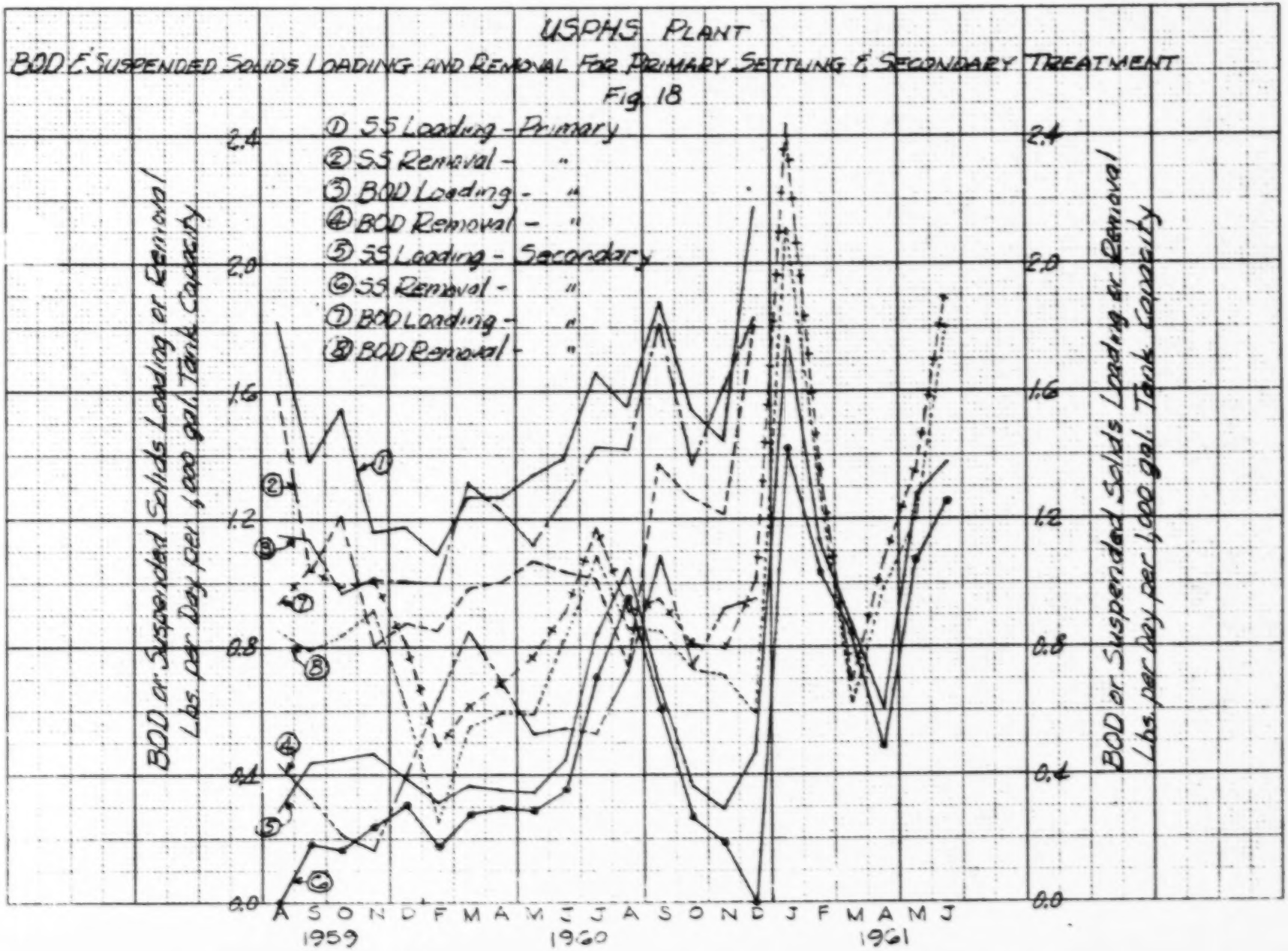


Fig. 17
TREND OF THE B.O.D. CURVES
U.S. Public Health Service
Plant Effluent
(Except Mar. 9 Columbus & May 17
Pilot Plant Samples)
Plot of data in Tools #10
Columbus Sewage
Plant Effluent
Mar. 9, 1960
Dec. 21,
1959
Apr. 4, 1960
Mar. 30,
1960
May 17, 1960
Raw Sewage
To Pilot Plant
Apr. 18
1960
Oct. 15
1960
Sept. 16,
1960
Oct. 26, 1959
Nov. 27, 1959
Mar. 9, 1960
B.O.D. - ppm or mg/l
Days Incubation @ 20°C.
0
10
20
30
40
50
60
70
1
2
3
4
5
6
7
8
9

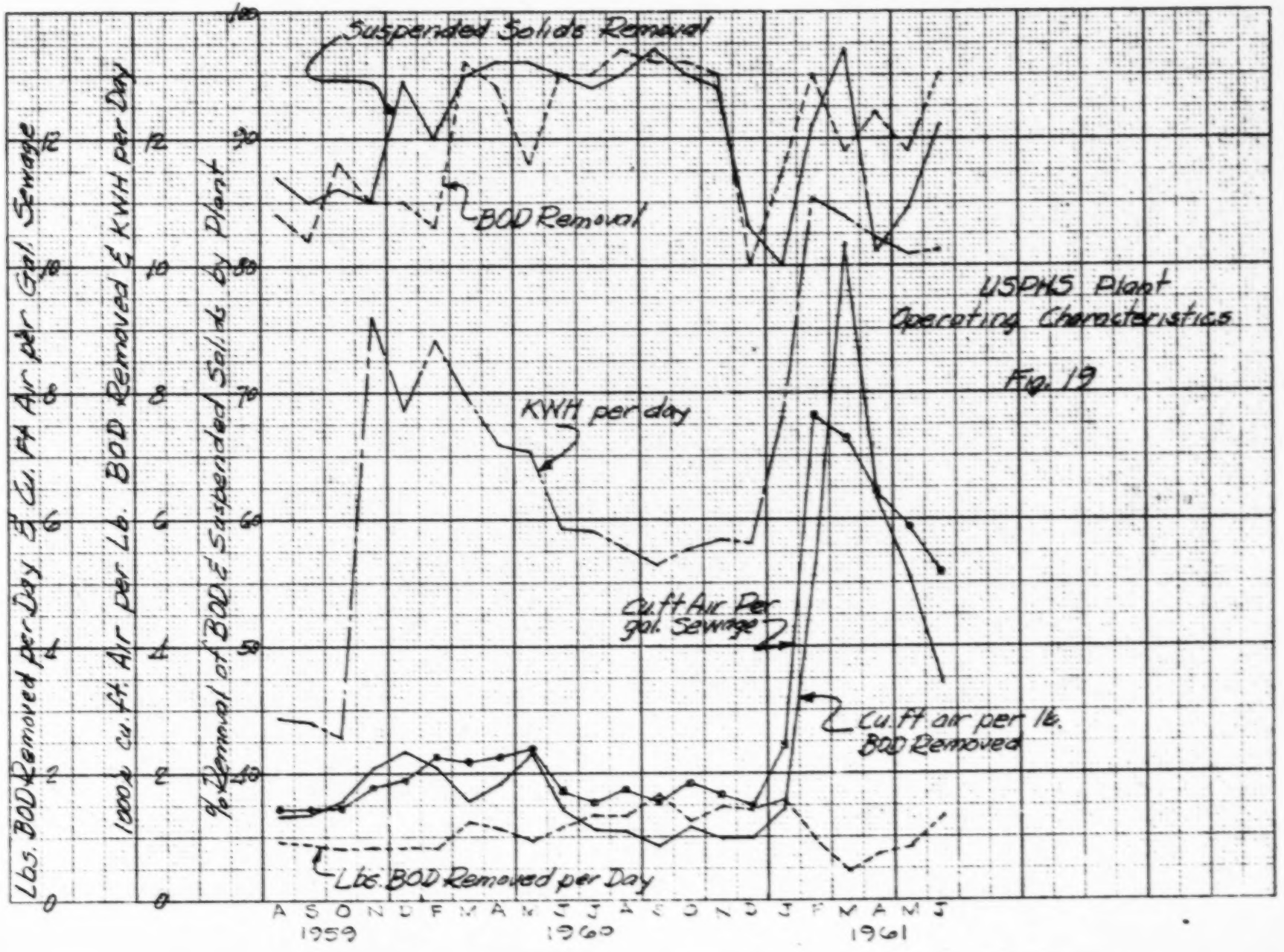
NO 340/ 20 DIETZGEN GRAPH PAPER
20 X 20 PER INCH

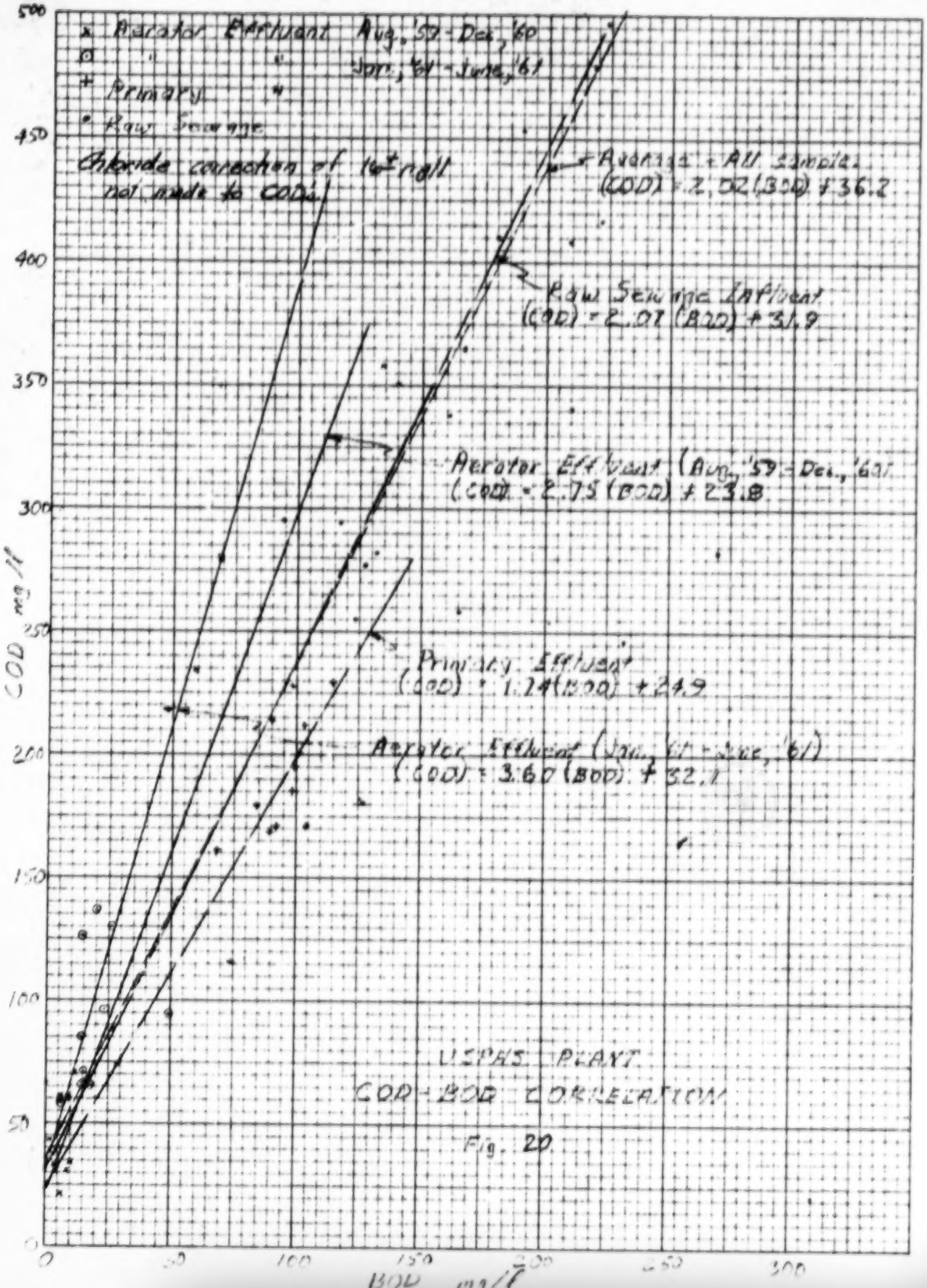
EUGENE DIETZGEN CO
MADE IN U. S. A.


USPHS PLANT
BOD & SUSPENDED SOLIDS LOADING AND REMOVAL FOR PRIMARY SETTLING & SECONDARY TREATMENT
Fig. 18
① SS Loading - Primary
② SS Removal - "
③ BOD Loading - "
④ BOD Removal - "
⑤ SS Loading - Secondary
⑥ SS Removal - "
⑦ BOD Loading - "
⑧ BOD Removal - "
BOD or Suspended Solids Loading or Removal Lbs. per Day per 1,000 gal. Tank Capacity
2.4
2.0
1.6
1.2
0.8
0.4
0.0
A S O N D J F M A M J J A S O N D J F M A M J
1959
1960
1961

NO. 340A -20 DIETZGEN GRAPH PAPER
20 X 20 PER INCH

EUGENE DIETZGEN CO.
MADE IN U. S. A.


Suspended Solids Removal
BOD Removal
KWH per day
Cu. ft Air Per gal. Sewage
Cu. ft. air per lb. BOD Removed
Lbs. BOD Removed per Day
USPHS Plant Operating Characteristics
Fig. 19
Lbs. BOD Removed per Day
1000's cu. ft. Air per Lb. BOD Removed & KWH per Day
% Removal of BOD & Suspended Solids by Plant
Cu. Ft Air per Gal. Sewage
A S O N D J F M A M J J A S O N D J F M A M J
1959
1960
1961



USPHS PLANT
COD - BOD CORRELATION

Fig. 20

EUGENE DIETZGEN CO.
NO. 340R-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH

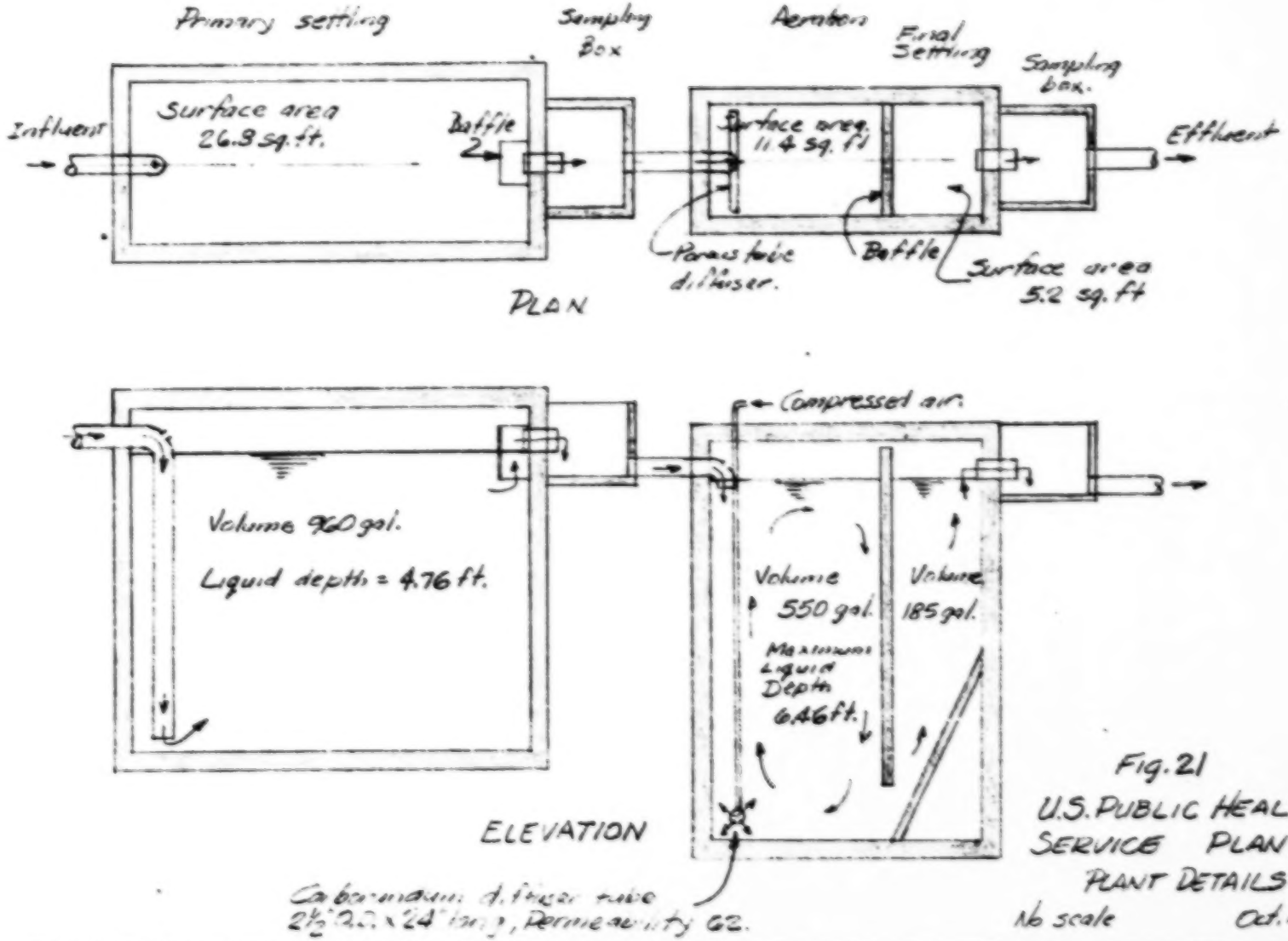


Fig. 21
U.S. PUBLIC HEALTH SERVICE PLANT
PLANT DETAILS
No scale Oct. 1959